PB82-241753

Sulfur Oxides Control Technology in Japan

(U.S.) Industrial Environmental Research Lab.
Research Triangle Park, NC

Prepared for

Committee on Energy and Natural Resources
(U.S. Senate)

30 Jun 78

U.S. Department of Commerce
National Technical Information Service
NTIS

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3. RECIPIENT'S ACCESSION NO.
		PB82 241753

4. TITLE AND SUBTITLE	5. REPORT DATE
Sulfur Oxides Control Technology in Japan. Interagency Task Force Report: June 30, 1978	June 1978
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Maxwell, M.A., Elder, H.W. and Morasky, T.M.	8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Interagency Task Force	10. PROGRAM ELEMENT NO.
	11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS Senate Committee on Energy and Natural Resources	13. TYPE OF REPORT AND PERIOD COVERED
	14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

16. ABSTRACT

This document summarizes the findings of a task force assigned to evaluate the current status of technologies for control of sulfur oxides in Japan, particularly the application of FGD or "scrubber" technology to coal and oil-fired utility and industrial power generating facilities in Japan. The application of FGD systems to coal-fired boilers is the focus of this report. Many tables and charts.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Sulfur oxides FGD scrubber coal fired - utilities, facilities oil-fired		EPA 68A

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS *(This Report)*	21. NO. OF PAGES
	20. SECURITY CLASS *(This page)*	22. PRICE

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

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NATIONAL TECHNICAL
INFORMATION SERVICE
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SPRINGFIELD, VA 22161

SULFUR OXIDES CONTROL TECHNOLOGY

IN JAPAN

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SULFUR OXIDES CONTROL TECHNOLOGY IN JAPAN

Introduction

At the request of the Honorable Henry M. Jackson, Chairman, Senate Committee on Energy and Natural Resources, the Environmental Protection Agency organized an interagency task force to evaluate the current status in Japan of technologies for control of sulfur oxides. Specifically, the task force set out to study the application of flue gas desulfurization (FGD) or "scrubber" technology to coal and oil-fired utility and industrial power generating facilities in Japan. The ultimate goals of the task force were three-fold:

(1) To evaluate the recent advances in Japanese scrubber technology

(2) To determine the basic circumstances surrounding the extremely successful Japanese scrubber experiences to date

(3) To ascertain to what extent these experiences could be applied to U.S. coal fired power generating facilities

The task force included the following individuals:

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Representatives of Senator Jackson's staff and the Department of Energy were also invited but were unable to participate due to prior commitments.

Dr. Jumpei Ando, a professor at Chuo University in Tokyo served as consultant, interpreter and guide during the visits. His knowledge of the subject area and facility with both languages were invaluable in promoting effective dialogue.

During the period January 30 - February 10, 1978, the task force visited a number of organizations in Japan which are directly involved in some facet of sulfur oxides control. The trip included visits to eleven scrubber plant sites as well as discussions with most of the major scrubber system suppliers, the Japan Environmental Agency, the Electric Power Development Corporation (EPDC), the Ministry of International Trade and Industry (MITI), and the Aichi Prefecture Environmental Research Center. Lists of plants and organizations visited are given in Tables 1 and 2.

The EPDC and Mitsui Aluminum plants were selected for study because of their similarity to U.S. utility scrubber applications (e.g., coal fired, limestone scrubbing, U.S. developed scrubber, etc.). The Wellman-MKK process at Nishinagoya and the Chemico-Mitsui process at Chiba were considered of importance because these processes employing U.S. technology have been applied at U.S. utility sites (e.g., Northern Indiana Public Service, Boston Edison and Potomac Electric Power). Interest in the MHI process applications at Owase and Shimonoseki resulted from the fact that MHI has provided about half of the lime/limestone scrubbing systems currently in operation in Japan. Finally, the Dowa and Kawasaki double alkali process applications were included because these technologies involve promising 2nd generation alternatives to lime/limestone scrubbing.

A detailed report covering each of the plants and organizations visited is being prepared for publication at a later date. In the interest of providing timely information on the most significant findings, however, this report primarily addresses application of FGD systems to coal-fired boilers in Japan. The report also provides an overview of the Japanese energy picture, the sulfur oxide regulatory framework, the general status of FGD in both the industrial and utility sectors, and concludes with a summary of findings. Details of the individual site visits to the coal fired plants are included as an appendix. The report draws not only upon the prior knowledge of the task force members and the observations noted during their stay in Japan but also from several literature sources cited as references.

Table 1. PLANTS VISITED IN JAPAN

Plant Owner	Plant Site	Plant Type	FGD Process	Capacity (MW)	Absorbent	By-Product	Year Operational
EPDC	Takehara	C, U	Babcock-Hitachi	250	$CaCO_3$	Gypsum	1977
EPDC	Takasago	C, U	Chemico-Mitsui	250 (2 units)	$CaCO_3$	Gypsum	1975/76
EPDC	Isoga	C, U	Chemico-IHI	265	$CaCO_3$	Gypsum	1976
Mitsui Aluminum	Omuta	C, I	Mitsui-Chemico	175	$CaCO_3$	Gypsum	1975
Mitsui Aluminum	Omuta	C, I	Chemico-Mitsui	156	Carbide lime	Sludge	1972
Idemitsu Kosan	Chiba	O, I	Chemico-Mitsui	160	MgO	Sulfur	1975
Chuba Electric	Nishinagoya	O, U	Wellman-MKK	220	Na_2SO_3	H_2SO_4	1973
Chuba Electric	Owase	O, U	MHI	375 (2 units)	$Ca(OH)_2$	Gypsum	1976
Chugoku Electric	Shimonoseki	O, U	MHI	400	$CaCO_3$	Gypsum	1977
Naikai	Tamano	O, I	Dowa	30 (eq)	$Al_2(SO_4)_3$-$CaCO_3$	Gypsum	1976
Dowa Mining	Okayama	A	Dowa	50 (eq) (2 units)	$Al_2(SO_4)_3$-$CaCO_3$	Gypsum	1974
Japan Exlan	Saidaiji	O, I	Kawasaki	80	MgO-$CaCO_3$	Gypsum	1976

C = coal, O = oil, U = utility boiler, I = industrial boiler, A = H_2SO_4 plant

Table 2. ORGANIZATIONS CONTACTED IN JAPAN

Organization	Discussion Sites
Aichi Environmental Research Center	Nagoya
Chemico	Omuta
Chiyoda Chemical Engineering & Construction Co.	Tokyo
Chubu Electric Co.	Nagoya, Owasa
Chugoku Electric	Shimonoseki
Dowa Mining Co.	Tokyo, Okayama
Electric Power Development Co. (EPDC)	Tokyo, Isogo, Takehara, Takasago
Gadelius Co.	Okayama
Idemitsu Kosan Co.	Chiba
Japan Environmental Agency	Tokyo
Japan Exlan Co.	Saidaiji
Kawasaki Heavy Industries (KHI)	Tokyo, Saidaiji
Kureha Chemical Co.	Tokyo
Ministry of International Trade & Industry (MITI)	Tokyo
Mitsubishi Heavy Industries (MHI)	Tokyo, Hiroshima, Owasa, Shimonoseki
Mitsubishi Kakoki (MKK)	Nagoya
Mitsui Aluminum Co.	Omuta
Mitsui Miiki Co.	Omuta, Chiba

Energy Supply/Usage Trends

Energy usage in Japan has increased rapidly during recent years and has been heavily dependent upon imported oil. The oil crisis of late 1973 and the serious inflation resulting therefrom have significantly affected Japan's energy and environmental policies. As shown in the scenario in Table 3, efforts are underway to shift the energy strategy away from imported oil which now constitutes more than 70 percent of Japan's total energy supply. In 1975 Japan imported nearly 3.0×10^8 kiloliters of crude oil containing almost 3.0×10^6 tons of sulfur. Since 90 percent of the sulfur in the crude "topping" process remains with the residual oil fraction, more than 40 hydrodesulfurization plants have been built since 1968 capable of treating around 30 percent of the sulfur rich residual oil. Combustion of the remaining untreated residual oil comprises about 75 percent of the total SO_x emissions in Japan. About one fourth of the residual oil is burned in utility boilers with the remainder spread among other industries.

Although Japan in the early 1960's mined over 50 million tons of domestic coal yearly, coal production gradually dropped to around 20 million tons/year as oil imports increased. Coal production is increasing, however, as a result of recent central government policy aimed at strengthening the coal mining industry and reducing dependence on oil imports. Use of domestic coal in the utility industry has been promoted by the Ministry of International Trade and Industry (MITI) through its "Sunshine" project and implemented by the Electric Power Development Corporation (EPDC), a government/industry funded corporation founded in 1952 to mitigate the serious power shortage in the post-war period of economic reconstruction. EPDC has constructed and is operating a number of coal-fired power plants equipped with FGD systems, each of which was visited by the task force. Even though Japan imports over 60 million tons of coal annually, all has thus far been used for coke production for the steel industry. Importing of coal for fuel has recently begun and is expected to increase as more coal-fired power plants are built. Imports of LNG as an ultra clean fuel are also increasing and will likely find greater application in the more heavily industrialized and polluted areas.

The "Sunshine" project was begun in 1974 in an attempt to assure a long term stable supply of clean energy for the future by promoting research and development work on new energy technologies. Energy technologies under development include solar, geothermal, coal liquefaction/gasification and hydrogen.

Table 3. ENERGY SUPPLY IN JAPAN

	1975		1985		1990	
	Amount	(%)	Amount	(%)	Amount	(%)
Hydro power (10^6 kW)	24.9	(5.8)	41.0	(3.9)	51.0	(3.9)
Conventional	17.8		22.5		26.5	
Pumped storage	7.1		18.5		24.5	
Geothermal (10^6 kW)	0.05	(0.0)	1.0	(0.3)	3.0	(0.7)
Domestic oil, gas (10^6 kl)	3.5	(0.9)	11.0	(1.7)	14.0	(1.7)
Domestic coal (10^6 t)	18.6	(3.3)	20.0	(2.1)	20.0	(1.8)
Atomic energy (10^6 kW)	6.62	(1.7)	33.0	(7.4)	60.0	(11.2)
LNG (10^6 t)	5.06	(1.8)	30.0	(6.4)	44.0	(7.7)
Imported coal (10^6 t)	62.3	(13.1)	102.0	(12.4)	144.0	(14.1)
for steel industry	61.8		86.0		104.0	
for fuel	0.5		16.0		40.0	
New energy (10^6kl)	0.0	(0.0)	2.3	(0.4)	13.0	(1.6)
Imported oil (10^6kl)	286.0	(73.4)	432.0	(65.5)	452.0	(57.1)
Total (10^6 kl equivalent)	390.0	(100.0)	660.0	(100.0)	792.0	(100.0)

Regulation of SO_2 Emissions in Japan

During the post-war recovery period, sulfur oxide emissions in Japan increased rapidly due largely to a sharp upswing in the combustion of sulfur containing fossil fuels which accompanied the rapid economic growth. As can be seen in Figure 1, however, since 1967 there has been a steady abatement of this problem reflecting the effects of environmental laws and standards, the use of low sulfur oil imports, the hydrodesulfurization of residual oil and the widespread application of FGD systems. Between 1970 and 1975, the volume of sulfur oxide emissions was reduced by 50 percent despite a 120 percent increase in energy consumption during that period as the regulation of SO_2 emissions became much more restrictive. The ambient SO_2 standard was tightened from 0.05 ppm (yearly average) to 0.04 ppm (daily average) in May 1973 with a target date of achievement by May 1978. Under this standard, the hourly average should not exceed 0.1 ppm. The standard is much more stringent than those in effect in the U.S. and West Germany.

The SO_x emission standard enforced by the central government is carried out under a program known as the "K-value system". Under this system, a specific allowable quality of SO_x emissions for each emitting source within a given geographical area is calculated by the following equation:

$$Q = K \times 10^{-3} He^2$$

where Q = allowable SO_2 emissions in Nm^3/hr

He = effective stack height in meters (actual stack height plus plume ascent distance)

K = constant specified for each of 17 geographical regions (different for new and existing sources)

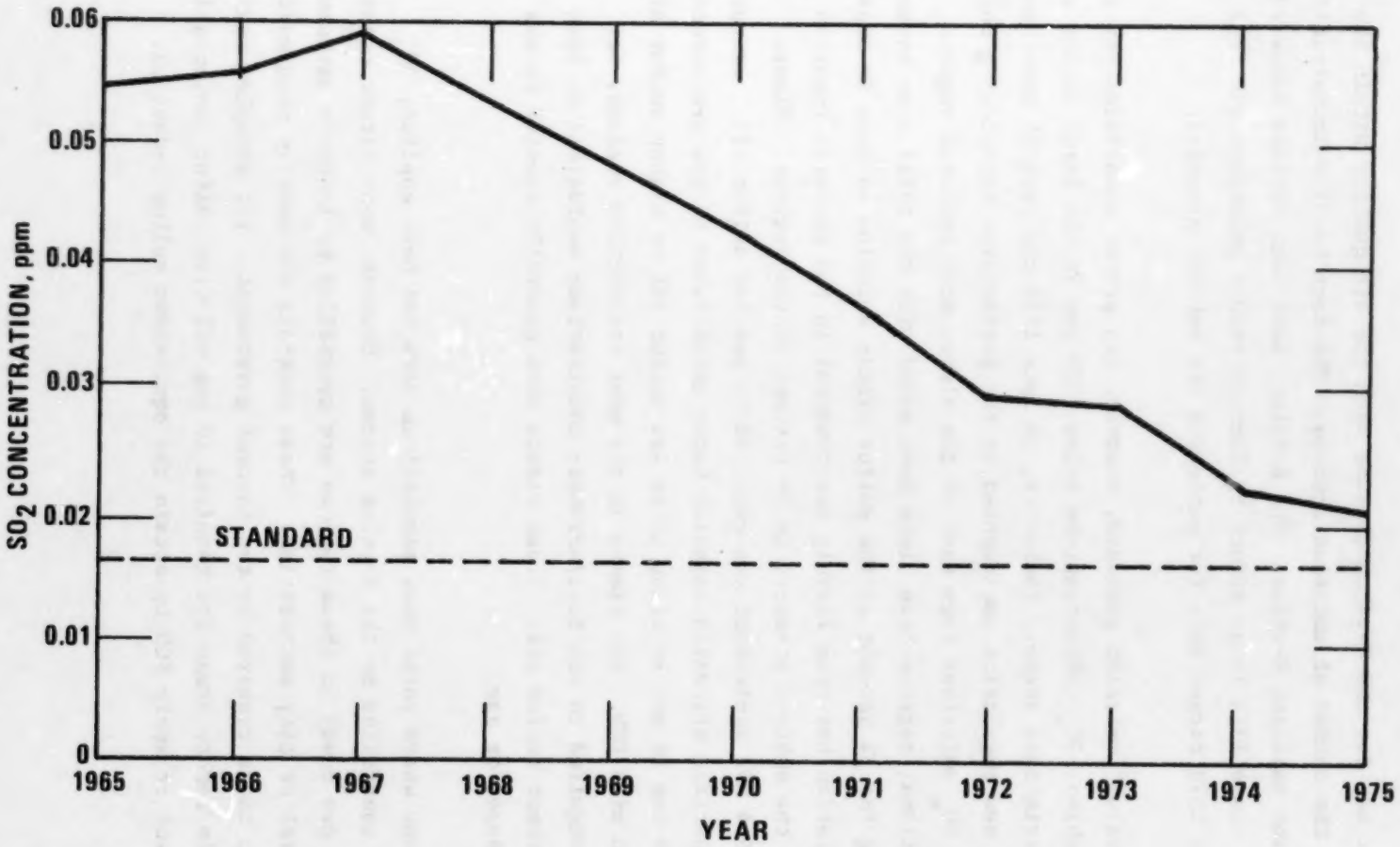

Figure 1. Trend in ambient SO_2 concentration in Japan, 1965-1975.

The level set for the K-value depends upon the air quality within the region and on the number of emission sources. The most heavily industrialized regions have the smallest K-value. The K-values have been revised downward almost yearly since 1974 in an effort to further reduce emissions and thus attain the May 1978 target date for achieving the ambient standard.

This "K-value" emission standard, however, has proven unsatisfactory in keeping the ambient SO_x concentrations below 0.04 ppm in the large cities and heavily industrialized areas. Therefore, in late 1974 the central government promulgated a new regulation implemented by the prefectures restricting the total mass of SO_x emissions from each of the eleven most polluted regions. Thirteen additional regions have since been added with the total area covered now accounting for 34 percent of the sulfur oxides emission sources in Japan. This new regulation has been largely instrumental in the recently reported attainment of the ambient standard in 98 percent of the regions. Plants smaller than 0.4 MWe equivalent are required to use low sulfur oil. Larger plants have specific allowable emission rates established by the prefectural governor which can be met by using ultra low sulfur oil or higher sulfur oil in combination with FGD. New plants in the most restrictive regions, for example, are required to use fuel/scrubber combinations equivalent to less than 0.079 percent sulfur oil. These plants have generally elected to use naphtha, kerosene, or gas.

For regions where total mass regulations have not been applied, SO_x emissions are controlled by the K-value system. However, most larger plants (particularly new ones) in these regions are controlled by industry agreements with prefectural or city authorities. These controls are usually much more stringent than those required by the central government. For example, many power plants in remote areas are required to use oil with sulfur contents less than 0.3 percent or apply FGD to attain the equivalent sulfur reduction.

One of the motivating factors behind the progress in SO_x abatement has been the "Pollution-Related Health Damage Compensation Law" which has been in effect since 1974. This law designates certain regions as polluted areas. Inhabitants of these regions who are diagnosed by doctors as having pollution related illnesses such as chronic bronchitis are designated as pollution-related patients. Plants emitting more than 5,000 Nm^3/hr of flue gas are assessed a tax based upon the total amount of SO_2 emitted, even though the emission regulations are being met. These tax proceeds are used to provide medical care for these pollution-related patients. This tax rate in the more heavily polluted areas has increased by a factor of 10 since 1975. Consequently, a number of companies presently meeting the regulations are now considering installing FGD plants because the resulting decrease in the tax may well compensate for the FGD costs under certain conditions.

Overall Status of FGD in Japan

Application of FGD systems in Japan has shown remarkably rapid progress since 1972 as shown in Figure 2. This growth rate can be largely attributed to several factors; (1) the elimination of the previous sizable cost differential between high sulfur fuels controlled by FGD and low-sulfur fuels and (2) the increasing confidence in the reliability of FGD system operation. However, this growth rate has begun to decline due to the following reasons:

(1) Ambient SO_2 concentrations in large cities and industrial districts have been reduced to the range 0.02-0.03 ppm, almost achieving the ambient standard of 0.016 ppm.

(2) The recent downturn in the Japanese economy has inhibited industry in building new plants. The majority of the FGD systems were built between 1970 and 1975 when the Japanese economy was growing rapidly.

(3) Saturation of the FGD by-product market and a decrease in the price differential between high sulfur and low sulfur oil have resulted in more extensive use of low sulfur fuels since Japan has little area available for discarding of waste products.

Of lesser importance is the fact that the stringent NO_x emission standards have resulted in a number of processes for simultaneous removal of NO_x and SO_x being developed. Rather than installing separate systems for NO_x and SO_x control, much of the industry is waiting for this new technology to be fully demonstrated.

Nevertheless, the present government policy of increased use of coal (much of it imported) for power production will necessitate the use of additional FGD systems in the future. Three new coal fired utility units totaling 1175 MW which will employ limestone-gypsum processes are presently under construction and are scheduled for start-up in 1979/1980.

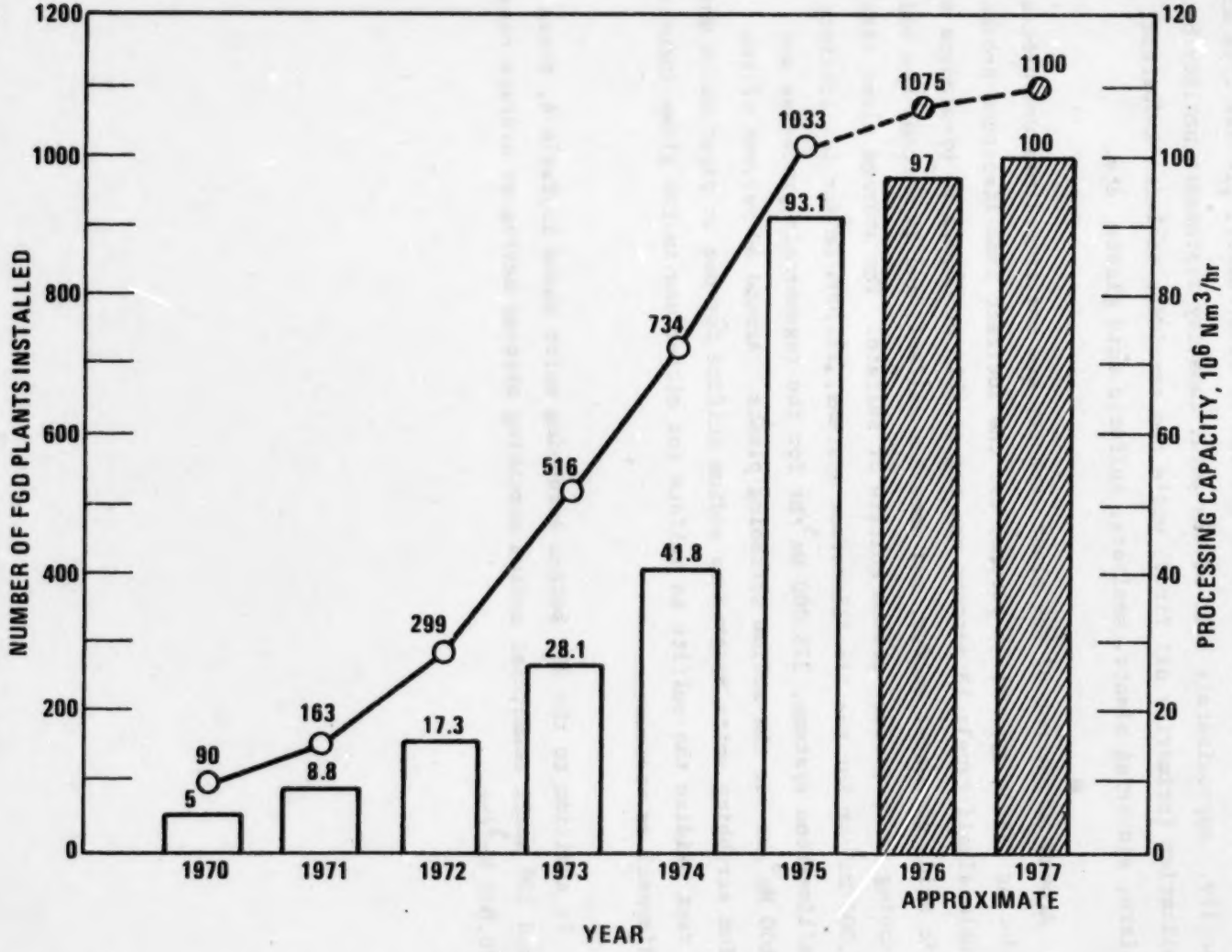

Figure 2. FGD growth rate in Japan, 1970 through 1977.

Over 500 major FGD plants having a combined capacity of about (90,000,000 Nm^3/hr about (31,000 MWe equivalent) were operational in Japan at the beginning of 1978. Table 4 summarizes these systems by constructor, process type and capacity. Approximately half of the total capacity represents utility boiler application (primarily oil fired) while the remainder includes industrial boilers, sintering plants, smelters, sulfuric acid plants, etc.

Around 50 percent of the plant capacity use the lime/limestone process producing usable gypsum; 16 percent use the indirect lime/limestone process (double alkali type); 13 percent use regenerable processes to by-produce sulfuric acid, elemental sulfur, and ammonium sulfate; and 24 percent use sodium scrubbing to by-produce sodium sulfite or sulfate. The average plant size was 427,000 Nm^3/hr for the lime/limestone systems, 291,000 Nm^3/hr for indirect lime/limestone systems, 378,000 Nm^3/hr for the regenerable processes and 59,600 Nm^3/hr for the sodium scrubbing plants. Around 80 percent of the sodium scrubbing units by-produce sodium sulfite for use in paper mills while the rest oxidize the sulfite to sulfate for either use in the glass industry or disposal as wastewater.

In addition to the 392 sodium scrubbing units shown in Table 4, there are around 500 small commercial sodium scrubbing systems having an average capacity of 20,000 Nm^3/hr.

Table 4. NUMBERS AND CAPACITIES (1,000 Nm^3/hr) of FGD PLANTS BY MAJOR CONSTRUCTORS

Plant Constructor	Lime/Limestone[1]		Indirect Lime/Limestone		Regenerable/Once through				Total	
		Gypsum[2]		Gypsum	H_2SO_4, S $(NH_4)_2SO_4$		Na_2SO_3 Na_2SO_4			
Mitsubishi Heavy Industries (MHI)	33	(18,270)					3	(292)	36	(18,562)
Ishikawajima H. I. (IHI)	17	(4,445)					79	(4,351)	96	(8,796)
Hitachi, Ltd.	13	(6,940)			2	(590)	15	(603)	30	(8,133)
Mitsubishi Kakoki (MKK)	2	(256)			13	(6,478)	41	(913)	56	(7,643)
Kawasaki Heavy Industries	4	(756)	6	(5,450)			7	(256)	17	(6,380)
Tsukishima Kikai (TSK)	1		4	(398)	1	(88)	40	(4,042)	46	(4,528)
Chiyoda Chemical Engineering & Construction			14	(4,459)					14	(4,459)
Oji Koei							57	(4,280)	57	(4,280)
Fuji Kasui Engineering	7	(3,954)					6	(270)	13	(4,224)
Kurabo Engineering			5	(413)	1	(18)	106	(3,751)	112	(4,182)
Mitsui Miike-Chemico	4	(2,744)			1	(500)			5	(3,244)
Ebara Manufacturing			11	(1,914)			10	(1,167)	21	(3,081)
Nippon Kokan (NKK)	3	(245)	1	(150)	2	(1,990)	6	(62)	12	(2,447)
Kureha Chemical							8	(1,431)	8	(1,431)
Showa Denko							5	(1,372)	5	(1,372)
Gadlius							8	(1,291)	8	(1,291)
Sumitomo (SCEC)-Wellman					6	(1,288)			6	(1,288)
Mitsui Metal Engineering	4	(1,006)			2	(130)			6	(1,136)
Kobe Steel	5	(1,125)							5	(1,125)
Japan Gasoline	1	(330)			1	(125)			2	(455)
Dowa Engineering			5	(453)					5	(500)
Niigata Iron Works			1	(185)					1	(185)
Mitsui Shipbuilding							1	(160)	1	(160)
Sumitomo Heavy Industries					1	(150)			1	(150)
Total	94	(40,171)	47	(13,422)	30	(11,357)	392	(24,241)	563	(89,138)

[1] Process type

[2] Byproduct

Status of FGD in the Japanese Utility Industry

As shown in Table 5, nine major private utility companies have produced about 70 percent of the total steam electric power generated in Japan largely using imported oil. The Electric Power Development Co. (EPDC) has been the primary consumer of domestic coal for power production. However, coal fired utility capacity presently accounts for less than 3 percent of the steam electric power produced. The total capacity of the utility steam electric generating industry (including those plants under construction) is 87,475 MW. This represents about 75 percent of the total utility power generated in Japan, with hydro and nuclear comprising the remaining 20 percent and 5 percent, respectively.

The present FGD utility capacity in service in Japan stand at 10,076 MW with another 3750 MW under construction or planned. This represents around 16 percent of the utility industry steam generating capacity. Comparable figures for the U.S. utility situation show 11,508 MW of FGD capacity in operation with an additional 44,171 MW under construction or planned. This corresponds to around 22 percent of the total U.S. coal fired power generating capacity.

Among the major power companies, Tokyo, Electric, Kansai Electric, and Chubu Electric supply power to the largest cities and industrial complexes in Japan. As may be seen from Table 5, these companies have elected to use low sulfur fuels such as naphtha and LNG in heavily polluted sections of their service areas due to their apparent concern that SO_2 emission standards may be further tightened beyond the point easily achievable by FGD. Recent regulations restricting total SO_2 mass emissions require large power plants in designated regions to maintain stack SO_2 outlet concentrations below 50 ppm, thus necessitating the use of low-sulfur fuel for reheat. More stringent standards may reduce the use of FGD as an effective control strategy. Conversely, Hokuriku Electric and Chugoku Electric have power plants more remotely located from the large cities and hence have a larger percentage of their capacity using FGD systems.

Table 6 shows a complete listing of FGD systems installed at power plants in Japan.

Table 5. CAPACITIES OF STEAM POWER PLANTS AND FGD SYSTEMS IN JAPAN

Power Company	Power generation (MW)			FGD (MW)			
	Existing	Under Construction	Total (A)	Existing	Under Construction	Total (B)	B/A (%)
Hokkaido	1,270	1,225	2,495	0	525	525	21.0
Tohoku	3,925	1,200	5,125	550	320	900	17.6
Tokyo	19,167	4,400	23,567	283	0	0	1.2
Chubu	9,933	3,800	13,733	970	0	970	7.1
Hokuriku	1,412	1,000	2,412	600	500	1,100	45.6
Kansai	10,672	1,200	11,872	930	0	930	7.8
Chugoku	3,777	1,800	5,777	1,350	700	2,050	36.8
Shikoku	2,687	450	3,137	900	0	900	12.5
Kyushu	4,500	2,700	1,376	1.376	250	1,626	22.6
EPDC	1,430	1,000	2,430	1,280	1000	2,280	93.8
Niigata	350	350	700	175	175	350	50.0
Showa	550	0	550	400	0	400	72.7
Toyama	750	0	750	250	0	250	33.3
Mizushima	462	0	462	156	0	156	33.8
Sumitomo	368	250	618	156	0	156	25.2
Sakata	0	700	700	700	0	700	100.0
Fukui	0	250	250	0	250	250	100.0
Others	5,512	375	5,887	0	0	0	0.0
TOTAL	66,775	20,700	87,475	10,076	3,750	13,826	15.8

Table 6. FGD SYSTEMS APPLIED TO POWER PLANTS IN JAPAN

Power company	Power station	Boiler No.	Boiler MW	FGD MW	Process developer	Absorbent, precipitant	By-product	Year of completion
Tohoku	Shinsendai	2	600	150	Kureha-Kawasaki	Na_2SO_3, $CaCO_3$	Gypsum	1974
"	Hachinohe	4	250	125	Mitsubishi H.I.	CaO	"	1974
"	Niigata	4	250	125	Wellman-MKK	Na_2SO_3	H_2SO_4	1976
"	Niigata H.	1	600	150	Mitsubishi H.I.	$CaCO_3$	Gypsum	1976
"	Akita	3	350	350	Kureha-Kawasaki	Na_2SO_3, $CaCO_3$	"	1977
Tokyo	Kashima	3	600	150	Hitachi-Tokyo	Carbon, $CaCO_3$	"	1972
"	Yokosuka	1	265	133	Mitsubishi H.I.	$CaCO_3$	"	1974
Chubu	Nishinagoya	1	220	220	Wellman-MKK	Na_2SO_3	H_2SO_4	1973
"	Owase	1	375	375	Mitsubishi H.I.	CaO	Gypsum	1976
"	"	2	375	375	"	"	"	1976
Hokuriku	Toyama	1	500	250	Chiyoda	H_2SO_4, $CaCO_3$	"	1974
"	Fukui	1	350	350	"	"	"	1975
"	Nanao	1	500	500	Not decided	"	"	1978
Kansai	Sakai	8	250	63	Sumitomo H.I.	Carbon	H_2SO_4	1972
"	Amagasaki	2	156	35	Mitsubishi H.I.	CaO	Gypsum	1973
				121	"	"	"	1975
"	"	1	156	156	"	"	"	1976
"	Osaka	3	156	156	Babcock-Hitachi	$CaCO_3$	"	1975
"	"	2	156	156	"	"	"	1975
"	"	4	156	156	"	"	"	1976
"	Kainan	4	600	150	Mitsubishi H.I.	CaO	"	1974
Chugoku	Mizushima	2	156	100	Babcock-Hitachi	$CaCO_3$	"	1974
"	Tamashima	3	500	500	"	"	"	1975
"	"	2	350	350	"	"	"	1976
"	Shimonoseki	2	400	400	Mitsubishi H.I.	"	"	1976
"	"	1	175*	175	"	"	"	1979
Hokkaido	Higashitomakomai	1	500	250	Not decided	"	"	1981

*Coal fired boilers. Others are for oil fired boilers.

Table 6. FGD SYSTEMS APPLIED TO POWER PLANTS IN JAPAN (Continued)

Power company	Power station	Boiler No.	Boiler MW	FGD MW	Process developer	Absorbent, precipitant	By-product	Year of completion
Shikoku	Anna	3	450	450	Kureha-Kawasaki	Na_2SO_3, $CaCO_3$	Gypsum	1975
"	Sakaide	3	450	450	"	"	"	1975
Kyushu	Karita	2	375	188	Mitsubishi H.I.	CaO	"	1974
"	Karatsu	2	375	188	"	$CaCO_3$	"	1976
"	"	3	500	250	"	"	"	1976
"	Ainoura	1	375	250	"	"	"	1976
"	"	2	500	250	"	"	"	1976
"	Buzen	1	500	250	Kureha-Kawasaki	Na_2SO_3, $CaCO_3$	"	1977
"	"	2	500	250	"	"	"	1978
EPDC	Takasago	1	250*	250	Mitsui-Chemico	$CaCO_3$	"	1975
"	"	2	250*	250	"	"	"	1976
"	Isogo	1	265*	265	Chemico-IHI	"	"	1976
"	Takehara	1	250*	250	Babcock-Hitachi	"	"	1977
"	Matsushima	1	500*	500	Not decided	"	"	1980
"	"	2	500*	500	"	"	"	1980
Niigata	Niigata	1	350	175	MHI	"	"	1975
Showa	Ichihara	1	150	150	Showa Denio	Na_2SO_3, $CaCO_3$	"	1973
"	"	5	250	250	Babcock-Hitachi	$CaCO_3$	"	1976
Toyama	Toyama	1	250	250	Chiyoda	H_2SO_4, $CaCO_3$	"	1975
Mizushima	Mizushima	5	156	156	Mitsubishi H.I.	CaO	"	1975
Sumitomo	Niihama	3	156	156	IHI	$CaCO_3$	"	1975
Sakata	Sakata	1	350	350	Mitsubishi H.I.	$CaCO_3$	"	1976
"	"	2	350	350	"	"	"	1977
Fukui	Fukui	1	250	250	Not decided	"	"	1977

*Coal-fired boilers. Others are for oil-fired boilers.

Summary of Findings

Both the United States and Japan have emerged as world leaders in developing and applying FGD technology. Application of FGD systems in Japan has generally preceded that in the U.S., however, because of the serious air pollution problems of the 1960's which resulted from the concentrated industry density and its proximity to population centers. Over 500 major FGD plants having a combined equivalent capacity of 27,500 MWe are presently in operation in Japan. Around half of this total represents utility boiler applications (predominantly oil fired), 98 percent of which produce usable gypsum from lime/limestone or double alkali FGD processes. Comparable figures for U.S. coal-fired utility applications show 11,508 MW of FGD capacity in service, of which 94 percent are lime/limestone processes producing a discardable sludge.

Seven of the plants visited used lime/limestone scrubbing systems which produced marketable gypsum for use in the wallboard and portland cement industries. The remaining four plants employ double alkali, Wellman-Lord and magnesia scrubbing techniques which produce marketable gypsum, sulfuric acid and elemental sulfur, respectively.

FGD technology is working well in Japan on both utility and industrial applications. Each of the eleven scrubber installations visited was designed for and routinely attained SO_2 removal efficiencies in excess of 90 percent (93 percent average) while achieving operabilities exceeding 96 percent (98 percent average). The performance of the coal fired units was not appreciably different from that of their oil fired or industrial counterparts with respect to SO_2 removal efficiency and scrubber system reliability. This outstanding performance is typical of that generally reported for other FGD systems.

The successful operation of lime/limestone scrubbers in Japan had been partially attributed earlier as a result of generally open loop operation created by purging large quantities of process liquids. The extent of liquid

blowdown, however, is variable; water removed from a Japanese lime/limestone scrubber system via the gypsum produced and liquid purged is often quite similar in quantity to that removed in a typical closed loop U.S. scrubber system employing ponding. In order to define the Japanese FGD systems on a basis comparable to those in the U.S., it is necessary to relate the quantity of gypsum produced by an FGD system to the amount of process liquids purged, thus establishing an effective pond disposal solids concentration. The ultimate settled solids concentration in a closed loop disposal pond serving a closed loop lime/limestone scrubbing system in the U.S. is generally in the 50 percent range. Table 7 lists all data presently available relative to liquid purge rates of lime/limestone FGD systems applied to Japanese utility boilers. It thus appears that many Japanese plants operate with much tighter liquid loops than some in the U.S. while others operate in a much more open loop fashion. It is significant that the effective pond solids concentration for the plants listed ranges from 29-77 percent with a midpoint of 53 percent. The data show that two of the three coal fired FGD plants are, thus, relatively tight in their water balance and could be considered closed loop if operated as a pond disposal system in the U.S. However, the coal fired unit with the lowest SO_2 inlet concentration is operated with a high blowdown rate, perhaps to insure the high performance needed at this plant.

A number of differences became apparent during the course of comparing the Japanese scrubber situation with that in the U.S.

The Japanese suppliers and users of FGD systems recognize and accept the fact that scrubbers basically involve chemical processes requiring carefully controlled operation by personnel specifically trained for this purpose. Many utilities including EPDC contract with subsidiary companies to supply scrubber system operating and sometimes maintenance services. These specially trained personnel are not rotated into the power plant for other duties as is generally the case with U.S. utilities.

Table 7. WASTEWATER PURGE FROM LIME/LIMESTONE SYSTEMS

Process	User	Plant Site	MW	Inlet SO_2, ppm	Waste Water, t/hr (A)	Gypsum, t/hr		Water Ratio (A+C)/(A+B+C)	Effective Pond Solids Concentration, %
						Solid (B)	Moisture (C)		
Lime									
Mitsubishi (MHI)	Chubu Elec.	Owase	750	1,600	6	30	3.0	0.23	77
Mitsubishi (MHI)	Kansai Elec.	Kainan	150	270	1.5	0.9	0.1	0.64	36
Mitsubishi (MHI)	Kyushu Elec.	Karita	188	600	3.7	2.2	0.2	0.64	36
Limestone									
Babcock-Hitachi	Chugoku Elec.	Mizushima	105	400	1.5	0.9	0.1	0.64	36
Babcock-Hitachi	Chugoku Elec.	Tamashima	500	1,480	4	19.0	1.9	0.24	76
Babcock-Hitachi	EPDC	Takehara	250*	1,700	12	11.2	1.1	0.54	46
IHI-Chemico	EPDC	Isogo	525*	400	20	9.0	1.6	0.71	29
Mitsubishi (MHI)	Chugoku Elec.	Shimonoseki	400	1,800	3	16.2	1.8	0.23	77
Mitsui-Chemico	EPDC	Takasago	500*	1,700	15	17.4	1.8	0.49	51

*Coal fired boilers

The design of scrubber systems in Japan appears to have generally been approached with a more conservative philosophy than that in the U.S. Specifications provided by the user utility to the scrubber system supplier do not appear to be more detailed than those supplied in the U.S. However, the user expects and, in fact, demands that the scrubber system supplied perform with a reliability compatible with that of the power generating plant. For example, EPDC requires the scrubber system supplier to correct at his expense any process/equipment problems that occur within a year after acceptance of the system. This philosophy has generally resulted in scrubber systems which are initially more expensive than their U.S. counterparts but which also have required less subsequent modifications and maintenance as a result of fewer operating problems. The fact that one supplier (MHI) has provided about half of the lime/limestone scrubbing systems in Japan has undoubtedly enhanced the reliability obtained.

The range of sulfur content of the coal burned in Japanese utility and industrial boilers is significantly but not drastically lower than that used in U.S. power generating systems. This sulfur content ranges from 0.7 percent at EPDC's Isogo plant to 2.4 percent at Mitsui Aluminum's Omuta Plant with the EPDC Takehara and Takasago plants each averaging around 2.0 percent. Because of the high ash content and intermediate heating values of the Japanese coals, the SO_2 concentration in the flue gas produced is equivalent to that produced from U.S. coals of somewhat higher sulfur content. For example, the 2.4 percent sulfur coal used in the Omuta plant results in an inlet SO_2 concentration approximately equivalent to a 3.0 percent sulfur Midwest or Eastern coal. Japanese FGD systems have been generally employed with flue gases having SO_2 inlets of 400-2300 ppm. It is significant that this range of inlet sulfur values covers many of the scrubber systems presently applied to U.S. coal fired utility boilers. However, there is no experience in Japan with the higher sulfur coals currently used in conjunction with many U.S. utility FGD systems. These higher SO_2 content flue gases are generally more inherently difficult to scrub due to mass transfer limitations.

Japan employs a stringent continuous monitoring and enforcement program to insure that utility and industrial sources are in continuous compliance with environmental regulations. Each prefectural government operates an environmental research center (subsidized by the central government), most of which are directly linked via telemetry systems to automatic monitoring stations located at major emission sources and key ambient sites. The existence of these monitoring systems likely has been instrumental in assuring that emission sources remain in constant compliance since violations would result in fines and/or forced shutdown of the source.

In some areas where the ambient concentration of sulfur oxides is considered to be sufficient to cause health problems, an SO_x emission tax has been levied. This tax system has been in effect since 1974 and applies to plants emitting more than 5000 Nm^3/hr of flue gas. For example, plants in the industrialized Chiba area are presently taxed at the rate of 345 yen/Nm^3 of SO_x emitted. For a typical 150 MW plant in this area emitting 100 Nm^3/hr SO_x after 95 percent SO_2 control, the daily tax would exceed 828,000 yen (~$4200 equivalent). A number of companies are presently considering installing FGD systems even though they are meeting the SO_x regulations using low sulfur fuel since the resulting reduction in tax obligation may more than offset the cost of FGD. These tax proceeds have been used for the medical care of patients diagnosed as having pollution related illnesses such as chronic bronchitis.

The last difference can best be expressed as the sincere cooperative spirit which appears to exist among Japanese industry (both users and suppliers) and the regulatory agencies. The major emphasis on installing pollution control equipment occurred during a period of strong economic growth when capital expenditures were easily absorbed. The central government has assisted industry in many instances in constructing pollution control facilities by providing low interest loans and allowing 7 year depreciation of the facilities. The need for environmental controls for sulfur oxides was at the crisis level in the late 1960's when Japan's scrubber installation program began to accelerate. The national goal of a cleaner environment has been accepted by the utility industry which has made a sincere effort to buy the best scrubbers available and to operate them in the manner for which they were designed. Intangible factors such as the Japanese culture/work ethic and the complex government/industry interrelationship are also of importance but perhaps the most difficult to define.

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Electric Power Development Company

Ishikawajima-Harima Heavy Industries Company - Chemico Process

Meeting on January 31, 1978 at 1:00 p.m. at EPDC's Isogo Station.

Attendees

EPDC: Yasuyuki Nakabayashi, Senior Power Engineer
Toshio Hayase, Deputy General Manager, Thermal Power Department
Atsusi Murata, Assistant Power Station Superintendent

Study Team: Jumpei Ando, M. A. Maxwell, T. M. Morasky, H. W. Elder

Background and Summary

The Isogo power station of EPDC is located in Yokohama, a heavily industrialized area near Tokyo. The environmental standards for the area are the most stringent in the country and SO_2 emission from the plant is limited to 48 Nm^3/day--equivalent to 60 ppm. Tokyo Electric burns LNG in a neighboring plant in order to meet the strict requirements so use of coal at the Isogo plant presents a real challenge. The plant consists of two 265 MW units built in the late 1960's. FGD units supplied by IHI-Chemico were added in 1976. The boilers normally burn coal but can also fire low-sulfur oil. A 50-50 mixture of coal and oil is used occasionally depending on fuel availability and cost. The coal is delivered by 5000-ton ships (300 vessels per year) from Hokiado and Kyushu; also about 50,000 tons per year of imported coal is used. The coal averages 6200 kcal/kgm and contains 16 percent ash. The maximum sulfur content is 0.6 percent and it normally ranges from 0.3 to 0.5 percent. The FGD system also is needed for particulate control. The plant is equipped with electrostatic precipitators that reduce the ash loading to 0.6 gm/Nm^3 and

further reduction to 0.05 g/Nm^3 is accomplished in the two-stage venturi scrubber. The boilers operate at about 75 percent load factor with reduction to 50 percent load during the night. The FGD system has effectively met the emission requirements and reliability has been near 100 percent after the startup period.

Process Description

The FGD system is similar to the Chemico design for U.S. installations except that limestone is the absorbent. A flowsheet for the process is shown in Figure 3. Two equipment trains each treat 900,000 Nm^3/hr. The system is a retrofit installation and previously existing ID fans supply gas to new booster fans to accommodate the FGD system pressure drop of 820 mm H_2O. The gas is cooled and cleaned in two-stage, fixed-throat venturi absorbers; the L/G in both stages is about 70 gal/1000 ft^3. The pH in the first stage is 5.4 and about 70 percent of the SO_2 removal takes place in this stage. The pH in the second stage is controlled at about 7. Overall stoichiometry is about 1.05. The limestone is purchased in pulverized form (100 percent minus 325) and slurried with fresh water to 15 percent solids. Limestone slurry is fed to the second-stage absorber and the effluent is pumped to the first stage for maximum utilization of the limestone. The recirculated slurry contains about 7 percent solids; dilution results from use of fresh water for mist eliminator wash. A bleed stream from the first stage absorber is treated in a forced oxidation system to produce gypsum. Facilities for sulfuric acid addition to adjust pH are provided but they have not been needed. Gypsum is dewatered in thickeners and centrifuges and except for a blowdown stream the clarified liquor is returned to the absorber system. The blowdown is needed primarily to control chloride concentration below 5000 ppm and the liquor is discharged through a waste water treatment facility where the suspended solids, BOD, COD, and pH are controlled. Dissolved solids are not regulated.

The scrubber exhaust gas passes through a chevron-type mist eliminator and is reheated to 120°C by direct combustion of low-sulfur oil; reheat adds about 10 ppm SO_2 to the stack gas.

System Design and Performance

The FGD system components are described in Table 8. The area available for the retrofit installation was small and the system was a tight fit. The general arrangement is shown in Figure 4 and a photograph is shown in Figure 5. The cylindrical venturi absorbers are of the Chemico type with pie-shaped chevron mist eliminator elements located in the horizontal position around the circumference of the vessel at the scrubber outlet. The superficial velocity below the fixed throat venturi section is about 10 ft/sec. The bottom of the absorber vessel serves as the recirculation tank; spare recirculation pumps are installed. The liquor rate is fixed so that during gas flow turndown the L/G exceeds the design rate of 70 gal/1000 ft^3. The mist eliminator for each unit is washed intermittently with fresh water at a rate of 21 tons/hr. The scrubber is constructed from mild steel and is flake lined (applied with brush). Piping is rubber lined. Pumps have stainless steel housings and silicon carbide impellers.

A total of nine centrifuges are installed for dewatering gypsum; at full load one is a spare for maintenance. Initially, flow distribution to the centrifuges was by orifice plates. Because of erosion problems, they have been replaced with control valves. The FGD systems have operated with a reliability of near 100 percent since startup in 1976. No. 2 boiler was shut down in March 1977 for its annual scheduled maintenance. No scaling was noted in the absorbers. However, some slight erosion on the recycle pumps was noted. No. 1 unit was inspected in May 1977. No major maintenance on the absorber was required as a result of this inspection. However, the impeller had to be repaired (hard facing applied) and a number of small valves were replaced because of erosion. This appears to be expected by the plant personnel and these valves will be replaced routinely. The limestone slurry feed valves are particularly subject to high erosion rates.

Of the three scrubbing systems operating on coal-fired boilers of EPDC the Isogo units operate with the most open loop concerning water balance. This may account in part for the high reliability of these scrubbers. About 10 ton/hr/unit is blown down to maintain chloride to less than 5000 ppm in the scrubbing liquor; this amount is equivalent to discharge of the product gypsum as a 29 percent slurry. The high water usage results in part from use of fresh water to make limestone slurry. Whenever recycle supernate from the process is used to make fresh slurry, removal efficiencies drop and limestone utilization rates decrease (probably the result of "blinding"). Plant personnel feel that perhaps the fly ash solubles affect system chemistry in some unknown manner.

The gypsum produced is low grade because of the high ash content (about 16 percent), and the relatively high moisture (15 percent). However, it is suitable for use in cement and is sold for the cost of delivery.

Three operators per shift are required to operate both FGD trains. In addition, two additional people are used on the day shift to perform routine maintenance and chemical analyses. Also, one operator per day is used to handle the gypsum intermittently and to handle limestone deliveries. The men operating the scrubbers are assigned full time and are not rotated into the power plant. This assures that the unit is operated as a chemical plant and also helps account for the high reliability.

Analysis of Significance

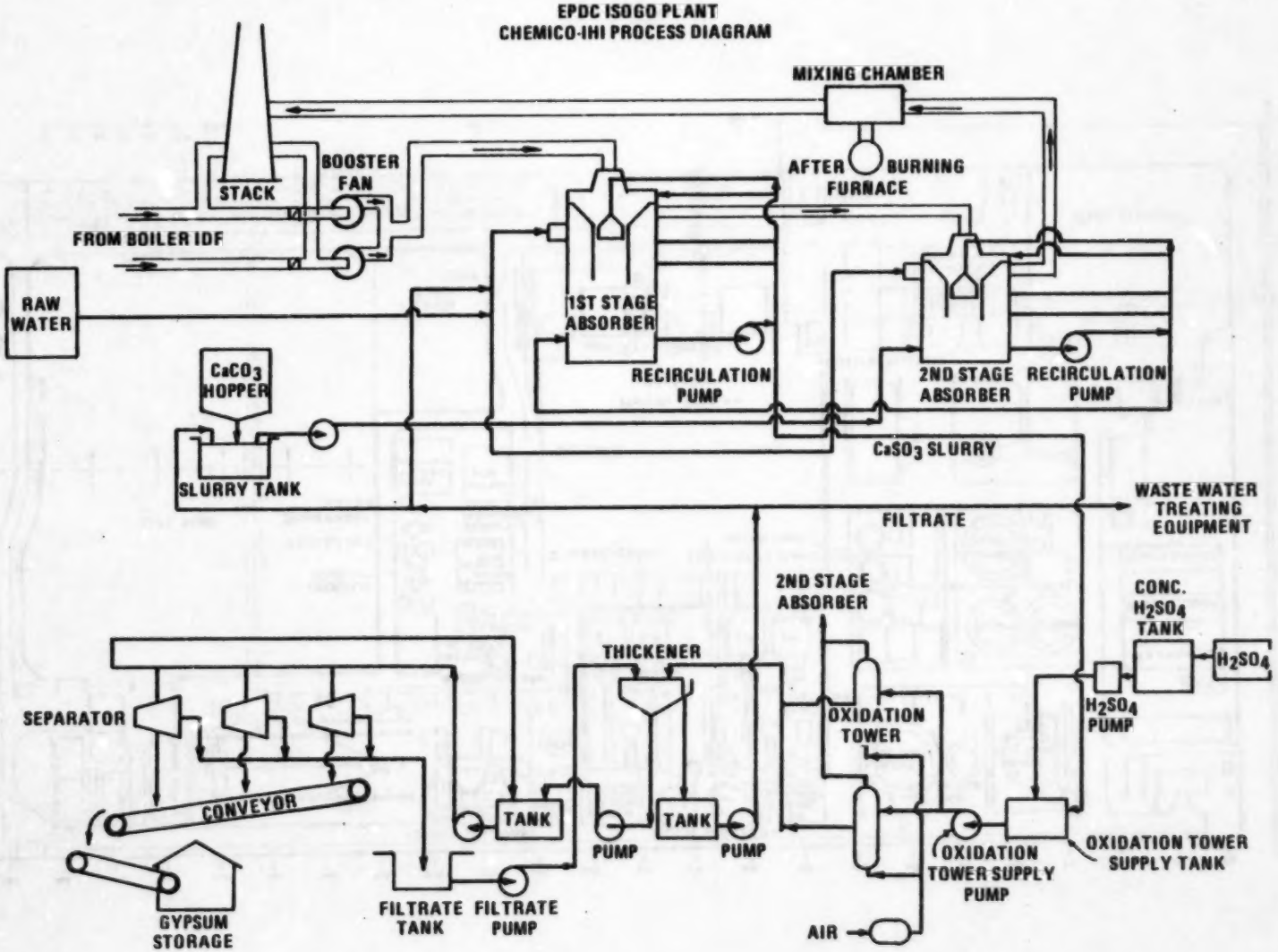
The Isogo experience is particularly significant to the U.S. situation for several reasons. The system design is quite similar to that provided by a domestic vendor; the power plant is fired with coal; the process uses limestone, and the regulations that must be met are severe. The high removal efficiency (93 percent average) with limestone in venturi scrubbers is impressive and the reliability approaching 100 percent is outstanding. Several factors appear

to be important to the successful operation. Probably most important is the low inlet SO_2 concentration. The 0.3-0.5 percent S coal allows use of limestone in a venturi system where either a more reactive absorbent (lime) or an absorber with more liquid holdup would be required with high-sulfur coal. Also, the extremely high L/G for a low SO_2 concentration decreases the need for dissolution of $CaCO_3$ in the absorber and reduces the "make per pass." The latter, in combination with the high removal efficiency and the low stoichiometry undoubtedly reduces the scaling potential prevalent with limestone scrubbing and high sulfur coal. The extremely fine particle size of the calcium carbonate also is helpful.

The relatively high use of fresh water is added insurance against high sulfate supersaturation levels and provides for good irrigation of mist eliminator surfaces. It also results in a high blowdown rate that requires extensive waste water treatment. It is significant that there is no regulation controlling dissolved solids content of effluents discharged to the sea. This is understandable where the receiving body of water is already saline, but the practice may not be prudent for fresh water streams such as the water courses adjacent to most U.S. power plants.

Use of "specialty" personnel for operation of the FGD system is particularly instructive. It is likely that a cadre of trained personnel whose primary responsibility is operation of a process-oriented system contributes in a major way to a successful program. The fact that the system design overwhelms the small amount of SO_2 that it sees certainly makes their job easier.

Figure 3.


EPDC ISOGO PLANT
CHEMICO-IHI PROCESS DIAGRAM
MIXING CHAMBER
AFTER BURNING FURNACE
BOOSTER FAN
STACK
FROM BOILER IDF
RAW WATER
1ST STAGE ABSORBER
RECIRCULATION PUMP
2ND STAGE ABSORBER
RECIRCULATION PUMP
$CaCO_3$ HOPPER
SLURRY TANK
$CaSO_3$ SLURRY
WASTE WATER TREATING EQUIPMENT
FILTRATE
2ND STAGE ABSORBER
CONC. H_2SO_4 TANK
H_2SO_4
H_2SO_4 PUMP
THICKENER
SEPARATOR
OXIDATION TOWER
CONVEYOR
TANK
TANK
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GYPSUM STORAGE
FILTRATE TANK
FILTRATE PUMP
AIR

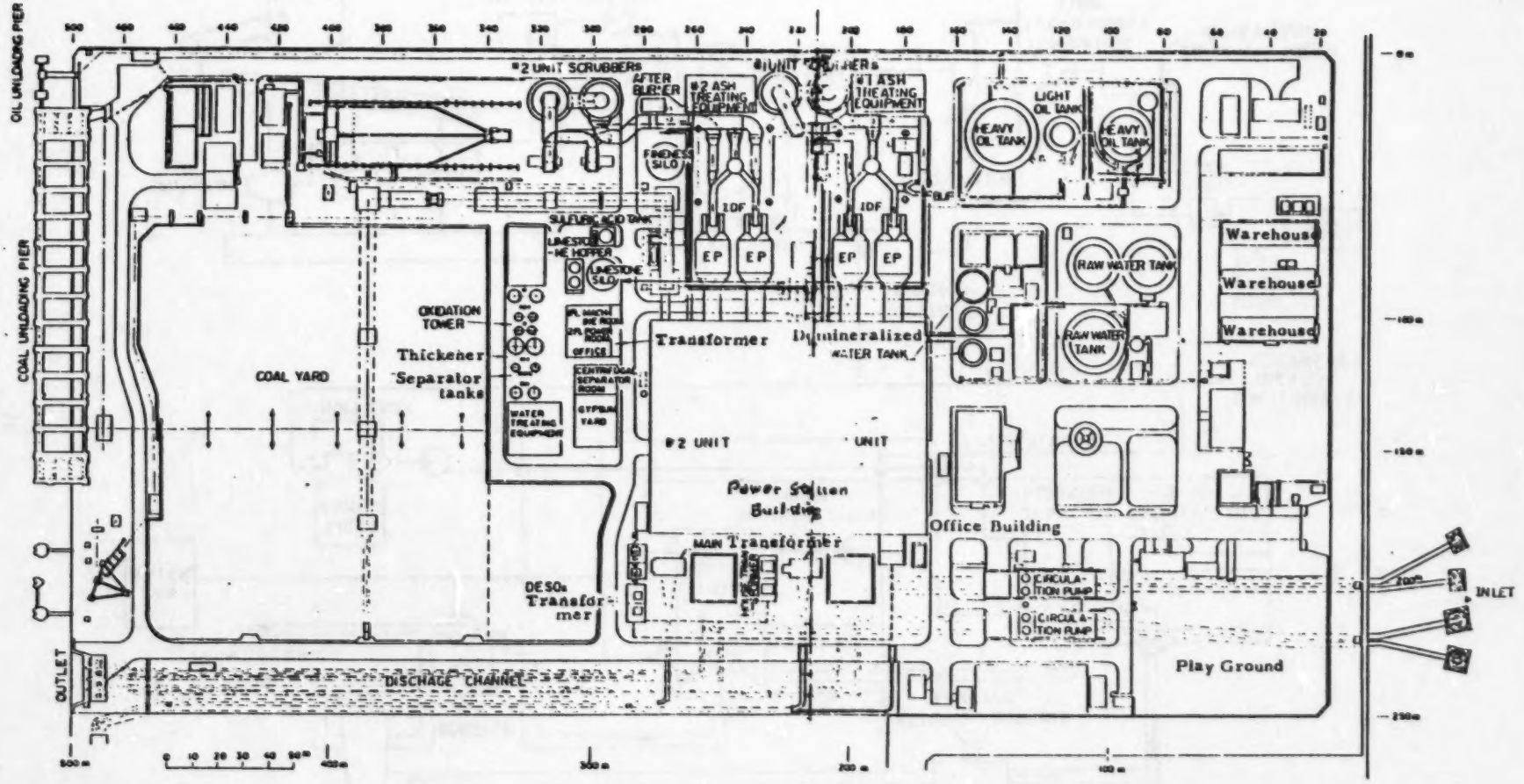

Figure 4. Isogo Station General Layout

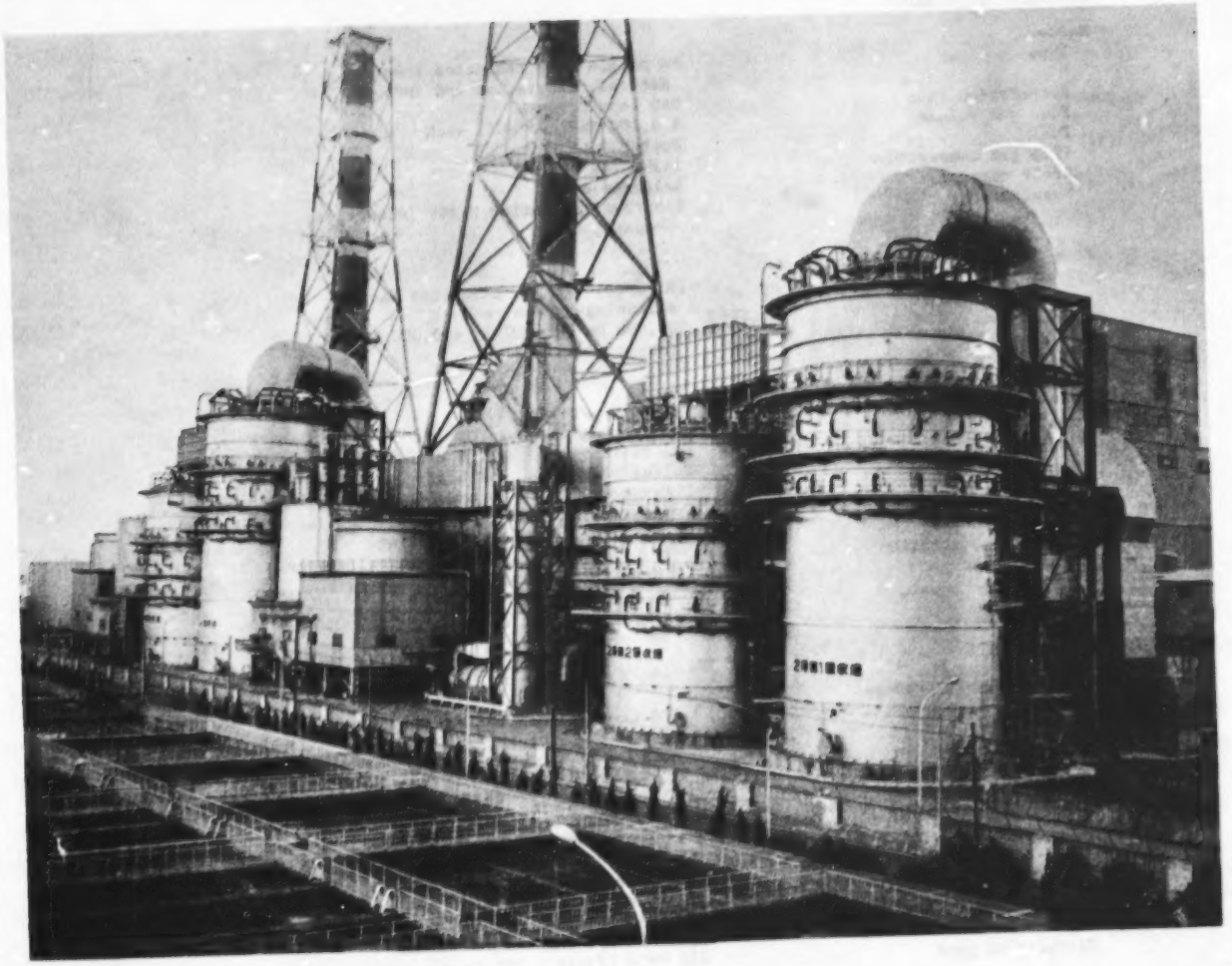

Figure 5.

Isogo Plant FGD System

Table 8. FGD SYSTEM SPECIFICATIONS

Plant Specifications

Boiler	
Type	FW single drum radiation reheat, natural circulation and indoor
Evaporation rate	840 tons/hr each
Flue gas volume	879,100 Nm^3/hr (MCR) each
Fuel	Coal
Flue gas temperature	143°C (AH outlet)
Draft control	Balanced draft
Manufacturer	Ishikawajima-Harima Heavy Industries, Company, Ltd.
Flue gas desulfurization system	
Type	IHI-Chemico type, limestone liquid scrubbing-gypsum recovery
Gas volume	900,000 Nm^3/hr (MCR); 450,000 Nm^3/hr (night hours) each
Efficiency of SO_2 removal	90%
Efficiency of dust removal	96.7%
Coal compositions	Inherent water 4.2% Ash content 16.0% Calorific value 6,200 kcal/kg Sulfur content 0.2-0.6%
Absorbent	Limestone 50 tons/day each (approx.)
Byproduct	Gypsum 120 tons/day each (approx.)
Gas reheating system	After-burning
Area of installation	3,000 m^2 (total/approx.)
Manufacturer	Ishikawajima-Harima Heavy Industries Company, Ltd.

Main Equipment

Absorbent supply process	
Limestone silo	1,000 tons (common use for No. 1 boiler and No. 2)
Makeup pump	3 sets
Absorption process	
1st stage absorber	1 stage venturi scrubber 1 set
2nd stage absorber	1 stage venturi scrubber 1 set
Boost up fan	Dual suction turbo-fan direct coupled to motor shaft
Gas volume	13,400 m^3/min each
Draft	820 mmAq
Motor power	2,400 kw x 2 sets/unit
Circulation pump	210 kw x 5/unit 195 kw x 5/unit
Gypsum production process	
Oxidation tower feed tank	Vertical cylindrical type made of carbon steel - 1 set
Oxidation tower	Vertical cylindrical type made of carbon steel - 2 sets/unit
Oxidation blower	Roots - blower
Air volume	50 Nm^3/min each
Draft	20,000 mmAq
Motor power	200 kw x 3 sets/2 units
Thickener	Sedimentation and concentration type - 1 set
Dehydrator	Screw decanter type
Solid content	1.05 tons/hr x 4 sets/unit
Gas reheater	Horizontal cylindrical type
After-burning furnace	2,600 kg/hr - 1 set

Electric Power Development Company

Mitsui-Chemico Limestone-Gypsum Process

Meeting on February 6, 1978 at 1:00 p.m. at EPDC's Takasago Station.

Attendees

EPDC: Mutsuaki Nakamura, General Manager, Takasago Power Station
N. Arai, Chief Engineer, Takasago Power Station

Study Team: Jumpei Ando, M. A. Maxwell, T. M. Morasky

Background and Summary

The Takasago Power Station of EPDC is located near Himeji on the Seto Inland Sea and consists of two 250 MW coal fired units employing the Mitsui-Chemico limestone-gypsum process. Unit No. 1 began commercial operation in July 1968 and Unit No. 2 in January 1969. The FGD system for Unit No. 1 became operational in February 1975 followed by the Unit No. 2 system in March 1976. Both FGD systems are nearly identical in design to the Unit No. 2 system at Mitsui Aluminum's Omuta Plant. The units burn a blend of domestic coals averaging 2.0 percent in sulfur content. The load profile of both units varies from 250 MW during peak daytime hours to 125 MW at night. Flue gas volume to each scrubber ranges from 840,000 Nm^3/hr to 500,000 Nm^3/hr, depending upon generating load. A photograph of the FGD system is shown in Figure 6.

SO_x emissions from the station were previously restricted to 400 Nm^3/hr by agreement with the local governments. However, under the more stringent total mass emission regulations effective April 1, 1978, the allowable emissions have been reduced to 243 Nm^3/hr (136 ppm) at full load.

The FGD systems were designed for and have consistently achieved average SO_2 removal efficiencies exceeding 93 percent while maintaining an operability of 99 percent. In addition, the scrubbers were designed to maintain particulate outlet concentrations below 0.05 g/Nm^3 with inlets from the ESP of 0.1 g/Nm^3. Key power plant/pollution control design and performance specifications are given in Table 9.

Process Description

A flow sheet of the process is shown in Figure 7.

Flue gas from the boiler is split into three streams and sent to the first stage scrubber (75 percent), pH control tower (20 percent) and oxidation tower. The flue gas exiting these vessels is then merged, passes through the second stage scrubber and is reheated directly (using 0.3 percent sulfur oil) to 85°C prior to passing into the stack. The process is characterized by the pH control tower and oxidation reactor which utilize SO_2 from the flue gas to lower the slurry pH to 5.8, thus increasing alkali utilization without using sulfuric acid. However, the system was originally designed for acid addition to the pH control tower.

The system does not employ a precooler although Mr. Arai (who previously worked at the Isogo plant) felt that including a quench section would have smoothed the operation.

Preground limestone (90 percent minus 325 mesh) is purchased, prepared on-site as a 15 percent slurry using centrate and thickener supernate and fed to the second stage scrubber at a stoichiometry of 1.0-1.05 that of the inlet SO_2. Process control is accomplished by measurement of flue gas volume and SO_2 concentration which automatically determines slurry make-up volume required. Fine tuning of the make-up feed rate is maintained by pH control in the second stage scrubber, which is operated at pH 6.2 and L/G of 6.5 l/Nm^3. Recycle slurry from the second stage is fed to the first stage scrubber which operates at pH 6.0 and L/G of 6.5 l/Nm^3. The recycle slurry is maintained at 5-6 percent solids. An unspecified catalyst was originally added to the second stage

scrubber reportedly to improve SO_2 removal efficiency, increase the oxidation rate, and obtain a higher quality gypsum required for wallboard. However, the catalyst is no longer used. The gypsum slurry from the oxidizer is pumped to a thickener, concentrated to a 20 percent slurry and dewatered by centrifuge, producing gypsum containing approximated 10 percent moisture.

Thickener overflow and the centrate are returned to the process for limestone slurry make-up absorber liquid level adjustments and mist eliminator washing. This supernate is also blown down (5 tons/hr for Unit No. 1, 10 tons/hr for Unit No. 2) to maintain chloride concentration below 8000 ppm.

Four pass chevron type mist eliminators are provided for the second stage scrubber which is sequentially washed with process liquor and fresh water.

Operating History

A detailed month by month operating history of the boilers/FGD systems is shown in Tables 10 and 11. Scrubber system reliability has averaged 98 percent since startup. As can be seen, the primary problem with Unit No. 1 involved scaling of mist eliminators which were washed with process liquor. This mist eliminator was replaced after about one year of operation and as a result operability has increased. The Unit No. 2 mist eliminator is now washed sequentially with fresh water and process liquor and has thus essentially eliminated the scaling problem.

Plant personnel indicated that very few erosion problems have been encountered with the system. The limestone slurry feed control valve is not rubber lined but fabricated of a tantalum/niobium alloy which resists erosion. Other materials of construction are comparable to those used in Mitsui Aluminum's Unit No. 2 FGD system at Omuta.

The present procedure is to operate the affected boiler at half load if the FGD system is shut down for corrective maintenance, provided that the FGD

system on the other unit is in operation. The emission regulations have been met in this fashion except on two occasions (September 1975 and February 1976) when the Unit No. 1 boiler was required to shut down for about 30 hours. Because of the stringent standards in effect after April 1978, however, future load reductions will not be possible and instead, the boiler will be required to shut down as a general practice until the scrubber problems are corrected.

The FGD system was originally designed for sulfuric acid addition for pH conditioning and a "catalyst" to encourage limestone utilization and gypsum oxidation. Presently neither acid nor catalyst is required in the system to obtain high limestone utilizations (gypsum contains only 4 percent calcium carbonate) or increase oxidation efficiency (gypsum product contains zero calcium sulfite).

The FGD systems are operated by a subsidiary company of EPDC. Three men/shift are required to operate both scrubber systems with three men on the day shift for maintenance (power plant personnel). Two additional men assigned to the day shift for waste water treatment and ash handling work part-time on the limestone receiving and gypsum handling/storage.

The capital investment for both FGD systems (total) was reported as 9.2 billion yen. Annualized operating costs for both units (including fixed charges and reheat) are 8.01 yen/kwhr of which 1.15 yen/kwhr are attributable to the FGD systems.

Analysis of Significance

The long term reliable performance of this plant is of significance to the U.S. utility situation since the design parameters are similar in several respects to those of many U.S. power plants employing FGD systems. Areas of commonality include (1) the use of coal as fuel in a moderately large sized boiler (250 MW) and (2) the use of a limestone scrubbing system based on U.S. developed scrubber technology.

In addition, the other factors cited for the Takehara plant are applicable here as well.

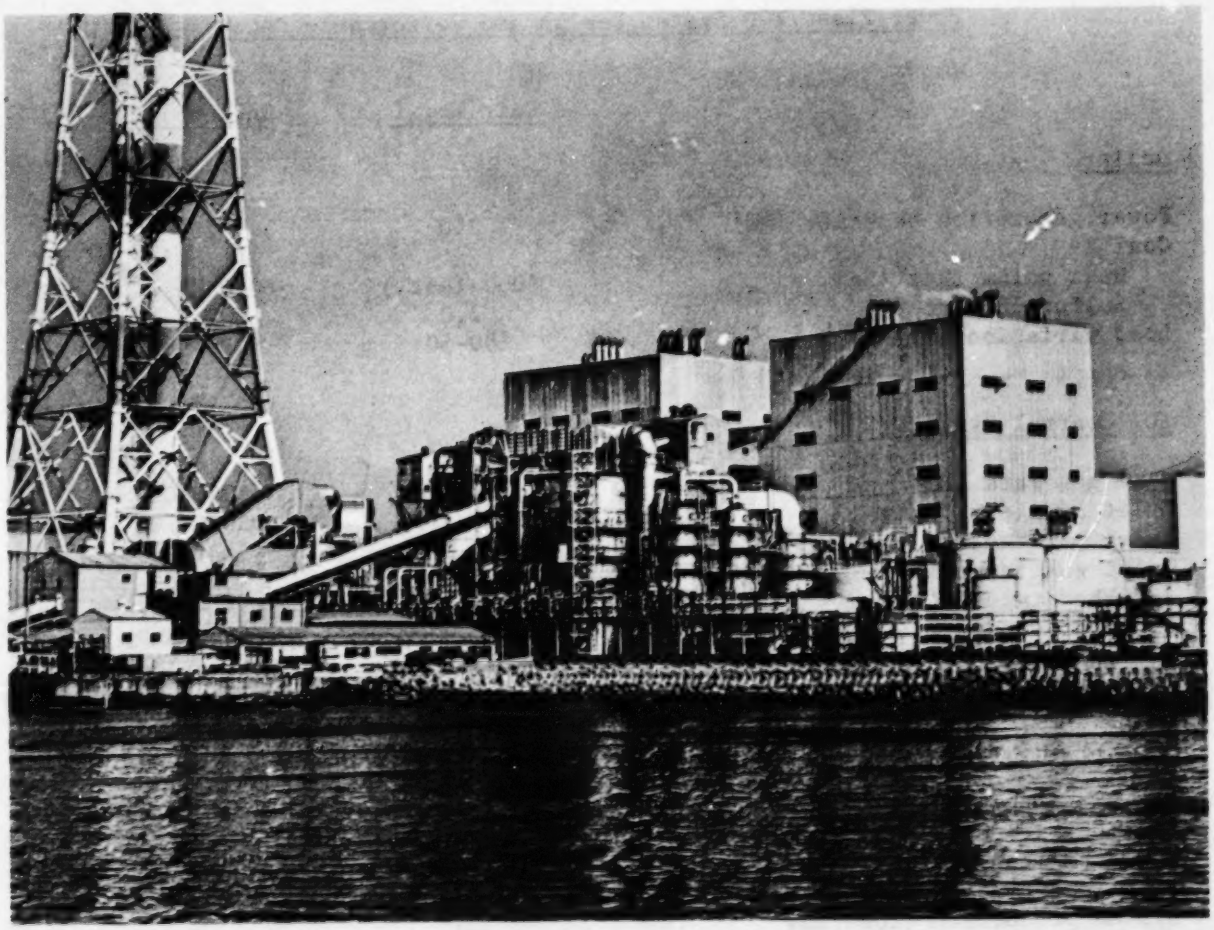

Figure 6.

Takasago Plant FGD System

Table 9

EPDC Takasago Station

Mitsui-Chemico SO_2 Removal System

Power Plant/FGD System Design and Performance Data

	Unit No. 1	Unit No. 2
Boiler		
Power generation capacity (MW)	250	250
Coal		
Heat value (kcal/kg)	6000 (est.)	6000 (est.)
Sulfur content (%)	2.0	2.0
Load variation (%)	100-50	100-50
SO_2 Control System		
Flue gas rate (Nm^3/hr)	799,000	799,000
Inlet SO_x (dry ppm)	1500-1700	1500-1700
Inlet particulate (g/Nm^3)	0.1	0.1
Inlet gas temperature (°C)	150	150
Scrubber type	2-stage venturi	2-stage venturi
Scrubber capacity (Nm^3)	842,000	842,000
Absorbent	limestone	limestone
Outlet particulate (g/Nm^3)	>0.05	>0.05
Outlet SO_x at stack (dry ppm)	>100	>100
Average SO_2 removal efficiency	93	93
Liquid purge rate (tons/hr)	5	10
Utility consumption		
Electric power (kw)	6500	6500
Water (tons/hr)	52	52
Limestone/lime (tons/day)	125	125
Gypsum production (tons/day)	230	230
Availability (%)	98.9	98.7

Figure 7.

EPDC TAKASAGO PLANT
MITSUI - CHEMICO LIMESTONE - GYPSUM PROCESS
FLOW DIAGRAM

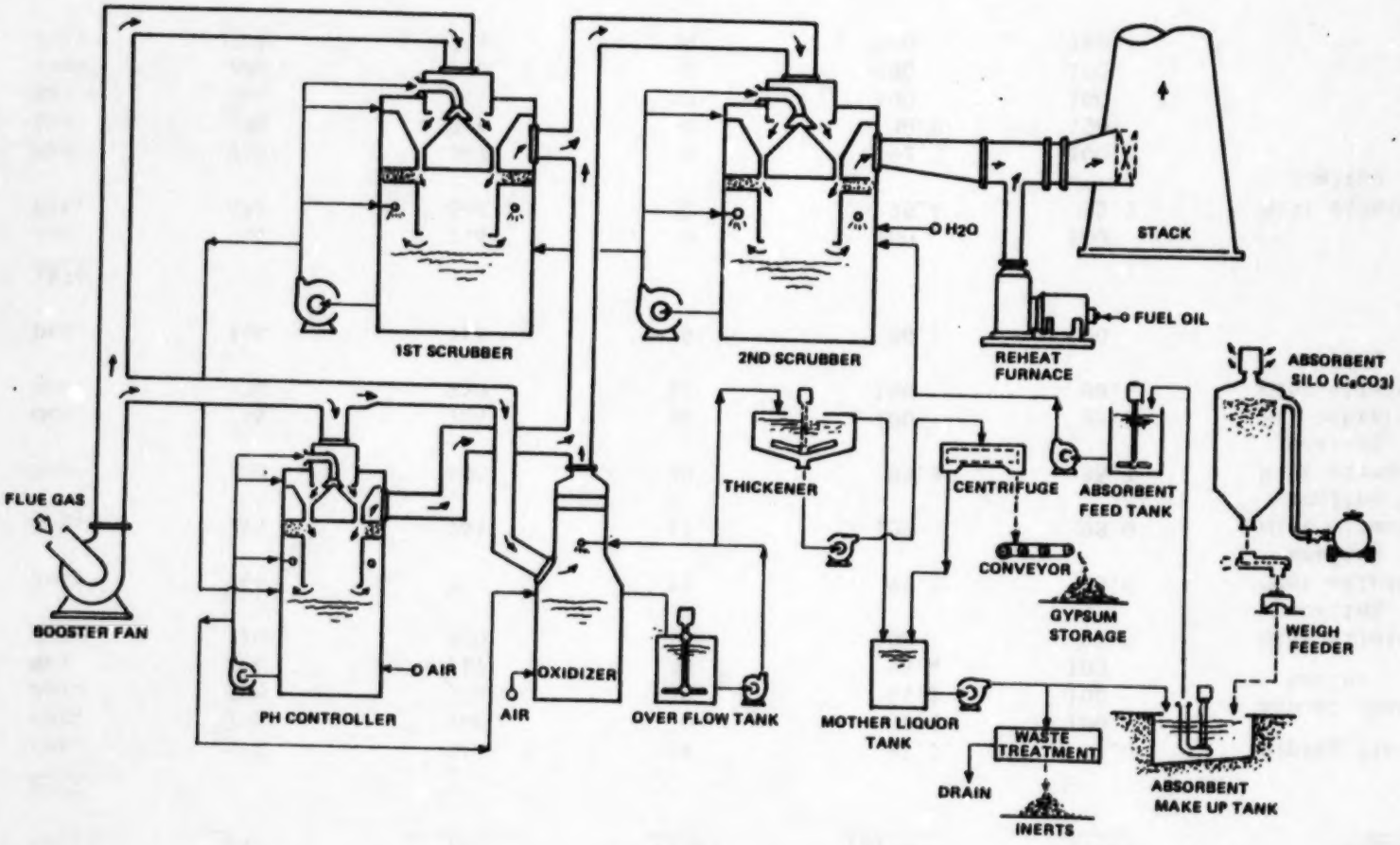

Table 10. OPERATING HISTORY OF THE NO. 1 UNIT, TAKASAGO PLANT

Month	Hours			Boiler Availability (%)(b)	FGD Operability (%)(c)	Remarks
	Total (A)	Boiler Operation (B)	FGD Stop (C)(a)			
1975						
Feb.	672	616	19	91.7	97.0	Piping flange leak
Mar.	744	360	0	48.4	100	
Apr.	720	318	0	44.1	100	Annual shutdown of boiler
May	744	717	0	96.4	100	
June	720	720	15	100	97.9	Mist eliminator scaling
July	744	743	15	99.9	98.0	Mist eliminator scaling
Aug.	744	744	15	100	98.0	Mist eliminator scaling
Sept.	720	690	30	95.9	95.7	Mist eliminator scaling
Oct.	744	744	36	100	95.2	Fan vibration
Nov.	720	720	11	100	98.4	Mist eliminator scaling
Dec.	744	715	29	96.1	100	
1976						
Jan.	744	744	0	100	100	
Feb.	672	664	32	95.4	95.3	Mist eliminator scaling
Mar.	744	687	0	92.3	100	
Apr.	720	219	0	30.0	100	
May	744	744	0	100	100	
June	720	720	0	100	100	
July	744	744	0	100	100	

(a) Due to troubles of FGD unit
(b) B/A (%)
(c) (A-C)/A (%)

Table 10. OPERATING HISTORY OF THE NO. 1 UNIT, TAKASAGO PLANT (Continued)

Month	Hours: Total (A)	Hours: Boiler Operation (B)	Hours: FGD Stop (C)(a)	Boiler Availability (%)(b)	FGD Operability (%)(c)	Remarks
1976						
Aug.	744	744	0	100	100	
Sept.	720	720	0	100	100	
Oct.	744	744	62	100	91.7	Cleaning of 1st stage scrubber
Nov.	720	720	5	100	99.3	Repair of duct
Dec.	744	744	8	100	98.9	Repair of spray pipe
1977						
Jan.	744	744	5	100	99.7	Cleaning of 1st stage scrubber
Feb.	672	672	0	100	100	
Mar.	744	0	0	0		Annual maintenance of boiler
Apr.	720	513	0	71.3	100	
May	744	744	10	100	98.2	Fan vibration
June	720	720	0	100	100	
July	744	717	0	96.2	100	Cleaning of 1st stage scrubber
Aug.	744	744	0	100	100	
Sept.	720	720	0	100	100	
Oct.	744	744	43	100	94.3	Cleaning of scrubbers and reactors
Nov.	720	720	0	100	100	
Dec.	744	744	0	100	100	
1978						
Jan.	744	744	0	100	100	Cleaning of 1st reactor

(a) Due to troubles of FGD unit
(b) B/A (%)
(c) (A-C)/A (%)

Table 11. OPERATING HISTORY OF THE NO. 2 UNIT, TAKASAGO PLANT

Month	Hours: Total (A)	Hours: Boiler Operation (B)	Hours: FGD Stop (C)(a)	Boiler Availability (%)(b)	FGD Operability (%)(c)	Remarks
1976						
Mar.	744	744	0	100	100	
Apr.	720	720	0	100	100	
May	744	216	0	29	100	
June	740	632	0	88	100	
July	744	744	0	100	100	Annual maintenance of boiler
Aug.	744	744	0	100	100	
Sept.	720	720	0	100	100	
Oct.	744	744	43	94.2	100	Duct cleaning
Nov.	720	720	0	100	100	
Dec.	744	744	5	100	99.3	Repair of gypsum conveyor
1977						
Jan.	744	744	0	100	100	
Feb.	672	672	79	100	88.3	Cleaning of pH controller
Mar.	744	744	10	100	98.7	Cleaning of duct and pH controller
Apr.	720	720	0	100	100	
May	744	384	0	51.6	100	
June	720	24	0	32.9	100	
July	744	744	0	100	100	
Aug.	744	744	0	100	100	
Sept.	720	720	0	100	100	
Oct.	744	744	0	100	100	
Nov.	720	720	78	100	89.1	Cleaning of pH controller and reactor
Dec.	744	744	0	100	100	
1978						
Jan.	744	744	0	100	100	

(a) Due to trouble of FGD unit
(b) B/A (%)
(c) (A-C)/A (%)

Electric Power Development Company

Babcock - Hitachi Limestone-Gypsum Process

Meeting on February 7, 1978 at 1:00 p.m. at EPDC's Takehara Station.

Attendees

EPDC: Mr. N. Ichihara, Manager, Takehara Station
Mr. K. Oe, Vice Manager, Takehara Station
Mr. Fujiyama, Chief, Maintenance, Takehara Station

Study Team: Jumpei Ando, H. W. Elder, M. A. Maxwell, T. M. Morasky

Background and Summary

The Takehara Power Station of EPDC is located near Mihara on the Seto Inland Sea and consists of two units. Unit No. 1 has a capacity of 250 MW with an annual load factor of 75 percent and is fired by domestic Kyushu coals blended on-site to achieve a 2.0 percent sulfur fuel with a 6000 K cal/kg heating value. Unit No. 1 was constructed in 1967 and was subsequently retrofitted with a Babcock-Hitachi limestone gypsum system which began commercial operation in February 1977. Unit No. 2 is an oil-fired unit constructed in 1974 having a 350 MW capacity. Unit No. 2 burns 1.0 percent sulfur oil and has no FGD system at present although this option is being considered in conjunction with a new 700 MW coal fired unit scheduled for commercial operation in 1982. This new unit will use imported coal (either Australia or China). The decision as to whether FGD or low S coal will be used will be made by the end of 1978 and will determine whether FGD will be needed on Unit No. 2. Key power plant/pollution control system design and performance specifications are given in Table 12. A photograph of the plant is shown in Figure 8.

Since the plant is located in an area having no large cities, the environmental regulations are relatively mild. SO_x emissions are restricted by the Central Government to 468 and 503 Nm^3/hr for Units No. 1 and 2, equivalent to 600 and 620 ppm respectively at full load. However, by virtue of an agreement with the city and prefectural governments, Unit No. 1 SO_x emissions are limited to 195 Nm^3/hr (240 ppm).

The Unit No. 1 FGD system has achieved an operability in excess of 97 percent reflecting only three forced scrubber outages since start-up. The system was designed for and has consistently achieved an average SO_2 removal efficiency exceeding 93 percent.

Process Description

The process flow sheet for Unit No. 1 is shown in Figure 9. Flue gas enters the scrubber from the induced draft fans that draw the gas from 98% efficient electrostatic precipitators. The gas contains approximately 200 mg/Nm^3 of particulate matter and 1,730 Nm^3/hr of sulfur dioxide. The scrubber system consists of two identical scrubbing trains and is designed to scrub about 800,000 Nm^3/hr. Flue gas upon entering the scrubbing system is split equally, each portion entering a prescrubber venturi section where the gas is quenched. The precooled flue gas then proceeds to a second stage scrubber containing perforated plates for good gas-liquid contact. Gas flow through each scrubber train is controlled by separate fans. Prior to exiting the second stage the flue gas passes through a horizontal mist eliminator (vertical gas flow) consisting of finned tube bundles. The cleaned gas is then reheated to 120°C using direct oil fired reheaters prior to exiting through a 200 meter stack. Total pressure drop across the scrubber system is reported to be 650 mm H_2O (230 mm H_2O in the prescrubber and 385 mm H_2O in the scrubber). Fresh water is used to sequentially wash the mist eliminator. A complete wash cycle is about 2 hours and requires about 5-10 ton/fresh water for each train.

The scrubbing system uses a limestone slurry of 10% solids. The L/G ratio in the second stage is about 7 liters/Nm^3. The slurry from the second stage recycle tank is bled to the first stage prescrubber. The slurry in this tank is recycled at an L/G of about 2 liters/Nm3. Slurry from this prescrubber recycle tank is continuously bled to a pH adjustment tank where sulfuric acid is added to lower the pH prior to the slurry being pumped to an oxidation tower. After passing through the oxidation tower the slurry is then bled to a thickener where initial solids separation occur and supernatant liquid is returned to both recycle tanks for solids control. The underflow is then pumped to centrifuges where final dewatering of the gypsum is accomplished by batch operation. The byproduct gypsum contains about 10 percent moisture and is sold for use in the cement and wallboard industries. Supernatant liquid from the centrifuges is pumped to the limestone preparation tank to slurry the limestone. This supernatant liquid contains substantial gypsum particles that act as seed crystals which help in controlling scale and size/type of gypsum crystals ultimately produced. In the second stage recycle tank slurry pH is controlled at 6.0 and in the prescrubber recycle tank pH is maintained at 5.0.

Process control is accomplished by measurement of flue gas volume and SO_2 concentration which automatically determines volume of make-up slurry required. Liquor flow rate is kept constant during gas turndown.

Energy requirements for the FGD system (excluding reheat) were reported as 3.1 percent of unit power generating capacity.

Plant operators routinely blend coal to maintain inlet flue gas having sulfur dioxide concentrations between 1550 and 1650 ppm. The plant has strict specifications for the pulverized limestone delivered dry to the plant site. Quality control of this limestone assures 95% through a 325 mesh, a minimum of 55.4 percent CaO and impurities limited to 1.14 percent. Supernatant liquid is continuously blown down at a rate of 10-15 ton/hr to maintain a chloride level of 3500 ppm in the slurry.

Operating History

Since start-up in February 1977, the scrubber system has shown a very high degree of reliability (98.6 percent), operating 5,396 hours until the boiler was shut down for its annual maintenance outage on September 30. During this period, the scrubber operation was halted three times while the boiler was operated at half load using a mixture of coal and low sulfur oil in order to meet the emission standards. On two of these occasions, one scrubber train was shut down for 70 hours to clean plugged pump strainers servicing the absorber slurry circulation tank. On the other occasion, both scrubber trains were shut down to remove scale from the reheater ductwork.

The strainer plugging problem was solved by moving the strainers outside the absorber for easy accessibility. The overall operability of the FGD systems during this period was 97.4 percent for two-scrubber train operation and 98.6 percent during one-scrubber train operation. Since this annual maintenance outage, no problems have occurred that have required a scrubber system outage.

The plant has experienced very few erosion/corrosion problems, likely due to the type of materials in use throughout the scrubber system. All tanks and piping are rubberlined, the absorber and ducts are all flake lined, the venturi's are constructed of acid resistant castable, the hot gas mixing chamber is built of castable refractory and the pumps (casing and impellers) and slurry control valves are made of a "special kind of stainless steel." The only point in the system that the plant personnel predict a problem with erosion is in the oxidizer feed line. However, they feel this can be routinely maintained by replacement whenever the unit is down for its annual maintenance.

The system makes use of a gate type damper manually inserted and bolted shut to isolate one train from the other in the event of maintenance requirements. Fresh water is used to wash the mist eliminators in the scrubber system. This was recommended to them "by experience." It is believed that they went to fresh water wash after the scaling experience in the mist eliminator.

The plant uses a subsidiary company to operate the scrubber systems as in the other EPDC plants. Two men/shift are required for scrubber operations plus one part-time person from the fly ash system to handle limestone deliveries and gypsum storage/loading. Three men are used during the day shift for scrubber system maintenance. Plant management indicated that they would like to reduce the maintenance staff to two persons but union problems presently present this. Plant operators are not rotated into the power plant for other duties.

The capital investment for the FGD unit (including the gypsum storage house) was reported as 7.2 billion yen. Unit No. 1 annualized operating and maintenance costs (including fixed charges and reheat) are 8.82 yen/kwhr of which 1.73 yen/kwhr was FGD system related. By comparison, the annualized operating costs for Unit No. 2 which burns a medium sulfur oil are 7.92 yen/kwhr.

Analysis of Significance

The Takehara FGD system had been in operation about 1 year at the time of the visit and although the operating time may be insufficient to assess long-term maintenance requirements, the performance has been outstanding. Both SO_2 removal efficiency and reliability have been excellent. This experience is relevant to the U.S. situation because the system employs design features similar to those offered by a U.S. supplier of limestone scrubbing systems. The water balance is relatively tight, comparable to closed-loop sulfite sludge pond systems in the United States, and the coal sulfur content is within the range encountered in many U.S. installations. In one U.S. system similar to the Takehara design operational problems with high-sulfur coal diminished when the utility switched to a lower sulfur coal.

An important process difference compared to U.S. experience is use of forced oxidation to produce gypsum. Recirculation of gypsum seed crystals undoubtedly reduces scaling potential in the absorber. Other factors that likely contribute to successful operation include the following:

1. The plant is conservatively designed.

2. Inlet SO_2 concentration is reasonably stable as a result of coal blending.

3. Limestone is purchased as a high-quality, finely ground absorbent.

4. Qualified personnel are permanently assigned to operate and maintain the FGD system.

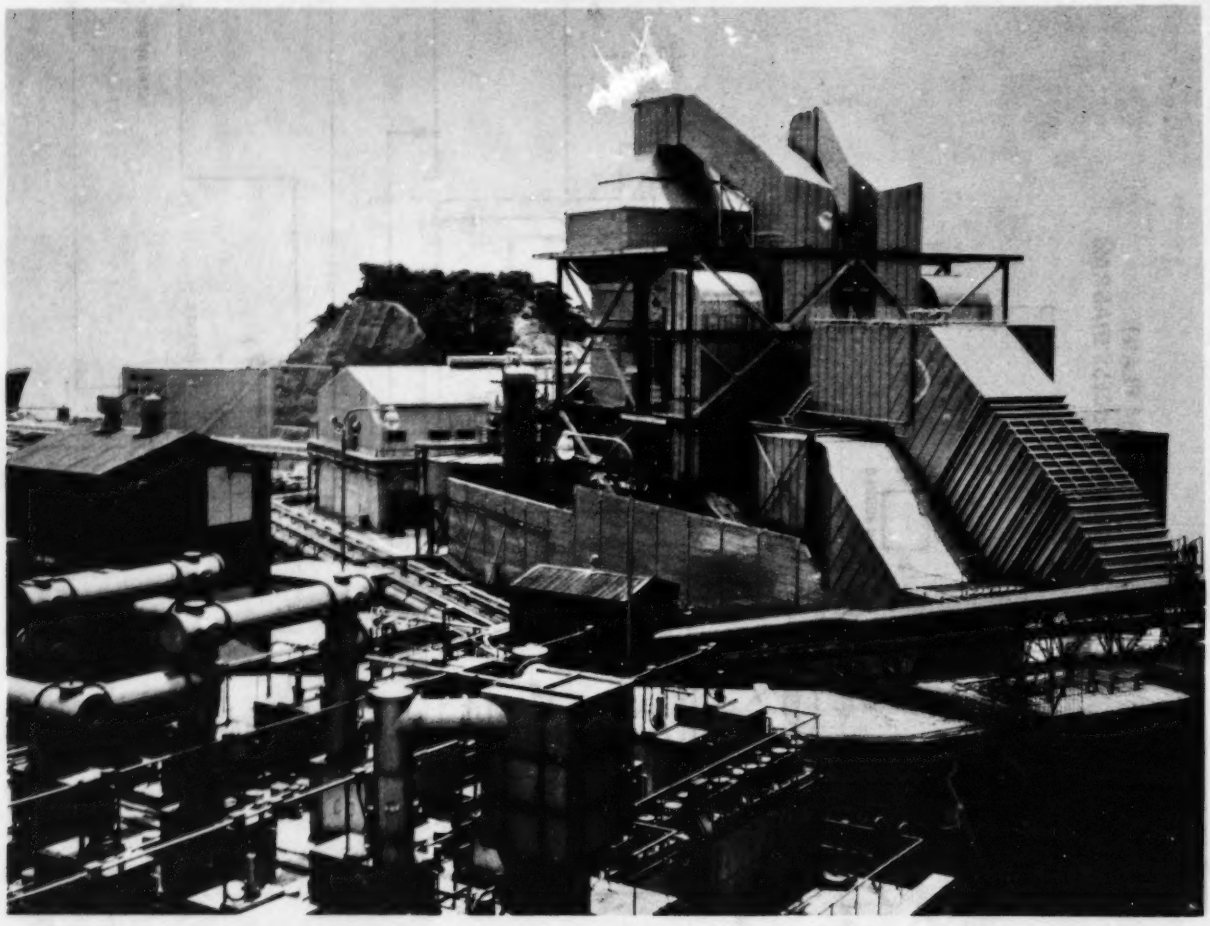

Figure 8.

Takehara Plant FGD System

EPDC TAKEHARA PLANT
BABCOCK-HITACHI PROCESS DIAGRAM

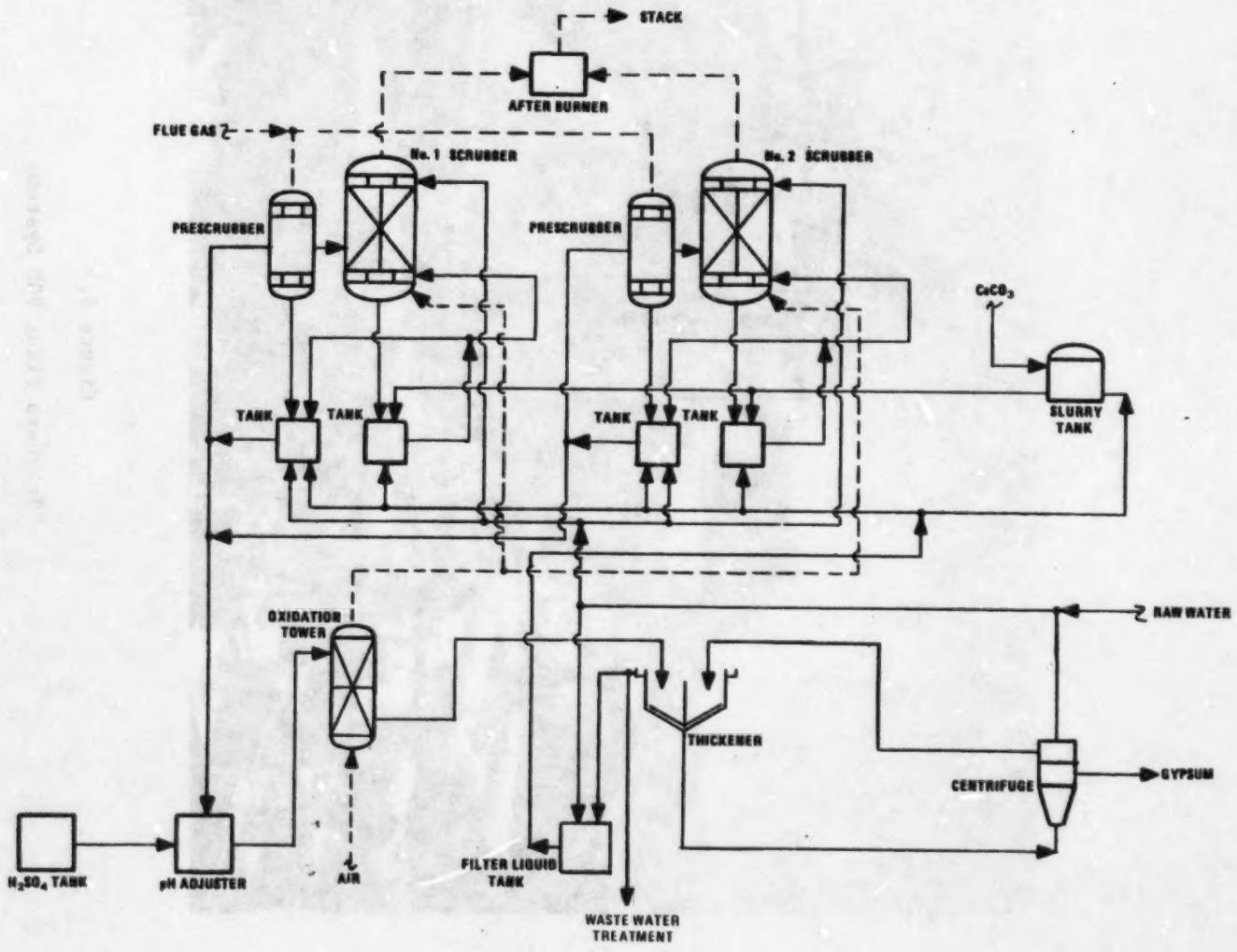

Figure 9

Table 12

EPDC Takehara Station

Babcock-Hitachi SO_2 Removal System

Power Plant/FGD System Design and Performance Data

Boiler

Power generation capacity (MW)	250
Electrostatic precipitator efficiency (%)	98
Coal	
Heat value (kcal/kg)	6000
Sulfur content (%)	2.0
Ash content (%)	23
Load variation (%)	100-40
Annual load factor (%)	75

SO_2 Control System

Flue gas rate (Nm^3/hr)	809,000
Inlet SO_x (dry ppm)	1500-1700
Inlet particulate (g/Nm^3)	0.36
Inlet gas temperature (°C)	140
Prescrubber type	venturi
Scrubber type	perforated plate
Scrubber capacity (Nm^3)	852,000
Absorbent	limestone
Outlet particulate (g/Nm^3)	>0.03
Outlet SO_x at stack (dry ppm)	>100
Average SO_2 removal efficiency (%)	93
Liquid purge rate (tons/hr)	10-15
Utility consumption	
Electric power (kw)	7800
Water (tons/hr)	56
Limestone/lime (tons/day)	130
Gypsum production (tons/day)	225
Availability (%)	97

Mitsui Aluminum Company, Ltd.

Mitsui-Chemico Lime/Limestone Processes

Meeting on February 9, 1978 at 9:00 a.m. at Miiki Power Plant, Omuta.

Attendees

Mitsui Aluminum Co.: Nagayasu Inagawa, Director, Miiki Plant
Akio Nagayoshima, Deputy General Manager, Miiki Power Plant
Koshi Okamoto, Chief, Environmental Section

Mitsui Miiki Machinery Co.: Eiki Kojima, Process Engineer

Chemico Engineering Co.: Masao Kodama, Manager, Engineering Section

Study Team: M. A. Maxwell, T. M. Morasky

Background and Summary

The Miiki Power Plant in Omuta was built in the early 1970's by the Mitsui Aluminum Company in order to provide a stable supply of electricity required for the aluminum smelter simultaneously constructed. The plant was designed to use locally mined Miiki coal (2.4 percent sulfur) for power production and is the largest privately owned power station in Japan. Unit No. 1 (156 MW) began commercial operation in May 1971 and was later equipped (April 1972) with a Mitsui-Chemico lime scrubbing system using carbide sludge waste from a nearby chemical plant in Denkikagaku. Unit No. 2 (175 MW) commenced commercial operation in July 1975 employing a Mitsui-Chemico limestone process which by-produces gypsum sold for use in the wallboard and portland cement industries. The power plant is linked to the Kyushu Electric Company power system to whom it occasionally sells surplus power. A photograph of the FGD system is shown in Figure 10.

Both units have achieved essentially 100 percent operability since start-up except for one 10 day outage of the Unit No. 2 scrubber for modifications to correct a mist eliminator carryover problem. Both units were designed for and have consistently achieved SO_2 removal efficiencies in excess of 90 percent. Key power plant/pollution control system design and performance specifications are shown in Table 13.

Process Description

Unit No. 1

The process flow sheet for Unit No. 1 is shown in Figure 11. The system consists of two scrubber trains, each capable of handling 75 percent of total flue gas capacity (512,000 Nm^3/hr). Of additional interest is the 25 MW slip stream prototype subsequently added to study the limestone/gypsum process prior to application to Unit No. 2. Although this prototype is no longer in operation, it reportedly could be restarted to provide 100 percent flue gas treatment in conjunction with one train should the second train require shut-down. Thus far this has not been necessary.

Flue gas passes through a two stage venturi scrubber (450 mm H_2O ΔP) where SO_2 and residual particulate are removed. The cleaned flue gas is reheated to 85°C prior to discharging through a 130 meter stack.

The system uses a mixture of wet (50-60 percent moisture) and dry (47 percent moisture) carbide lime which is adjusted to a final slurry concentration of 15 percent. Make-up slurry feed rate is manually controlled by recycle slurry pH which is maintained at 8 (as opposed to 6.8 design). Recycle slurry is normally maintained at around 5-6 percent suspended solids by weight. Liquid/gas ratio for each stage is around 40 gal/1000 ACFM. Delay tank residence times for the first and second stages were reported as 20 minutes and 4 minutes respectively. A bleed stream from the first stage delay tank is transported to a settling pond where the supernatant liquid is returned to the

process for carbide lime make-up, absorber liquid level adjustments, and mist eliminator washing. Four stage chevron type mist eliminators are provided for both first and second stages and are intermittently washed with fresh water and recirculated pond liquor. Gas velocity through the mist eliminator is around 2.7 meter/sec.

Unit No. 2

The process flow sheet for Unit No. 2 is shown in Figure 12.

Flue gas from the boiler is split into three streams and sent to the first stage scrubber (75 percent), pH adjustment tower (20 percent), and oxidation tower (5 percent). The three streams are then recombined, pass through the second stage scrubber and are reheated to 85°C prior to passing into a 180 meter stack.

Preground limestone (98 percent purity, 325 mesh) is purchased, prepared onsite as a 15 percent slurry using thickener overflow, and fed to the second stage scrubber at a stoichiometry of 1.0-1.05 times that of the inlet SO_2. Process control is accomplished by measurement of flue gas volume and SO_2 concentration which automatically determines volume of make-up slurry required.

The second stage scrubber is operated at pH 6.0-6.3 and liquid/gas ratio of 40 gal/1000 ACFM. Recycle slurry from the second stage is fed to the first stage scrubber which operates at pH 5.6-5.9 and liquid/gas ratio of 40 gal/1000 ACFM. Delay tank resistance time for first and second stage was reported as 7 minutes each.

The pH of the bleed slurry from first stage scrubber is adjusted to 5.4-5.8 in the pH "controller" as SO_2 is absorbed. This technique replaces the H_2SO_4 addition required in other processes to solubilize calcium sulfite prior to oxidation. The slurry is then pumped to a conventional oxidizer for conversion to gypsum.

A small amount of catalyst is added to the second stage scrubber reportedly to improve the SO_2 removal efficiency, increase the oxidation rate and obtain a higher quality gypsum crystal required for wallboard. Mitsui claims that at low pH in the oxidizer the catalyst promotes oxidation while inhibiting oxidation at the higher pH values in the second stage scrubber.

The gypsum slurry from the oxidizer is pumped to a thickener, concentrated to a 20 percent slurry and dewatered by centrifuge producing gypsum containing 5-8 percent moisture.

The thickener overflow and centrate are returned to the process for limestone slurry make-up, absorber liquid level adjustments and mist eliminator washing. Recycle of gypsum seed crystals from thickener into the absorber reportedly aids in controlling size and type of gypsum crystals ultimately produced.

Mist eliminator design and washing techniques are the same as for Unit No. 1.

Operating History

Both FGD systems have operated quite well while achieving essentially 100 percent operability. The only FGD system forced outage occurred on Unit No. 2 for 10 days during November 1975 when modifications were made to correct a mist eliminator carryover problem. Otherwise, both systems have been in continuous operation except during the annual power plant maintenance outages.

Both units were designed for and have consistently achieved SO_2 removal efficiencies exceeding 90 percent. Current local emission regulations require that the outlet SO_2 concentration at the stack (after reheating) not exceed 230 ppm. Therefore, the units are operated to maintain a stack outlet SO_2 concentration less than 200 ppm. There have reportedly been no violations of this regulation during the operating life of the plant.

Other than the early mist eliminator problem, few operational difficulties have apparently been encountered. Some erosion of rubberlined butterfly control valves in Unit No. 2 was noted. Consequently, diaphragm valves are considered preferable. Materials of construction of the FGD system components are shown in Table 14.

Compared to the EPDC Takesago and Takehara plants, Unit No. 2 operates with a more open water loop (27 percent solids effective pond concentration) having a 20 ton/hr liquor purge rate to control chloride content at 1000 ppm.

The Miiki coal used is blended at the mine and has an average heating value of ~6400 kcal/kg. The resulting blend is then mixed at the power plant with around 30% low grade "slime" coal (coke fines) having an average heating value of 4000 kcal/kg. This final mixture has an average heating value of 5800 kcal/kg and an average sulfur content of 2.4 percent.

Table 15 shows a typical chemical analysis of the process reagents/products.

Originally, 8 persons/shift were assigned to operate both scrubber systems (including limestone receiving, gypsum production and gypsum shipping). Six persons/shift now handle these functions but will reportedly decrease to 4 persons/shift this fall. In addition, 2 persons are assigned to maintenance on the day shift. Operators spend about 1 year assigned to the FGD units prior to being rotated into power plant functions.

The investment and annualized costs reported for the FGD systems are shown in Table 16. Investment figures for Units No. 1 and 2 represent 1972 and 1974 costs, respectively, except for the prototype plant which represents 1974 costs. Annual costs are for the April 1976 - March 1977 period and were reported to comprise 18 percent of the total cost of producing power.

Analysis of Significance

The Mitsui-Chemico limestone/gypsum process appears to possess important advantages relative to more conventional limestone scrubbing processes producing a throwaway sludge requiring ponding or fixation. The high SO_2 removal and limestone utilization efficiencies obtained using a two stage venturi absorber are quite attractive for U.S. applications. However, the capital costs for the process will likely be somewhat higher than for conventional limestone systems due to the "pH controller" and complex oxidizer. This facility is considered particularly relevant to many U.S. coal fired applications of limestone systems where 2300 ppm SO_2 inlet concentrations are encountered.

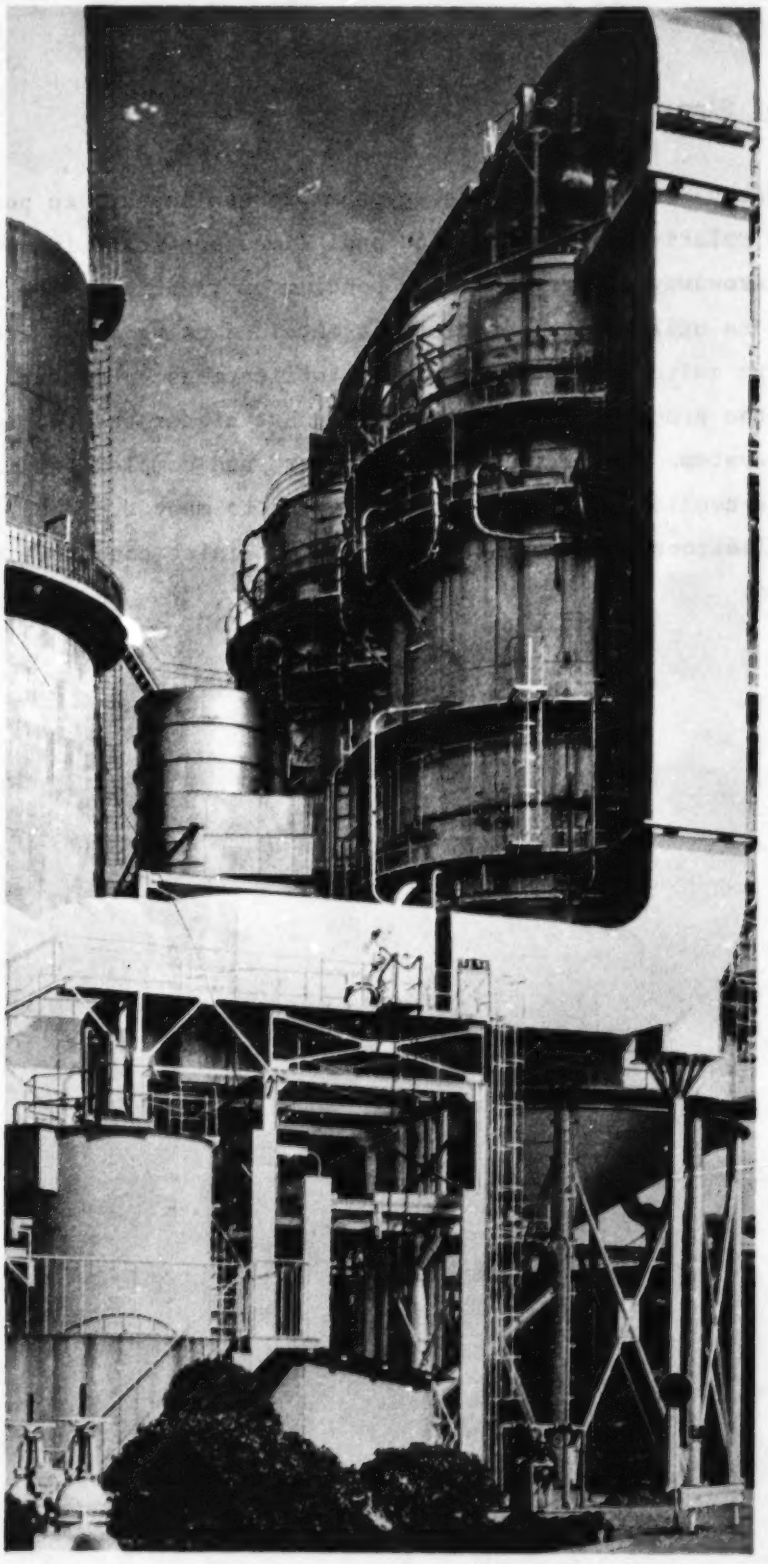

Figure 10.

Mitsui Aluminum Plant FGD System

MITSUI ALUMINUM COMPANY
MITSUI - CHEMICO PROCESS DIAGRAM
UNIT NO. 1

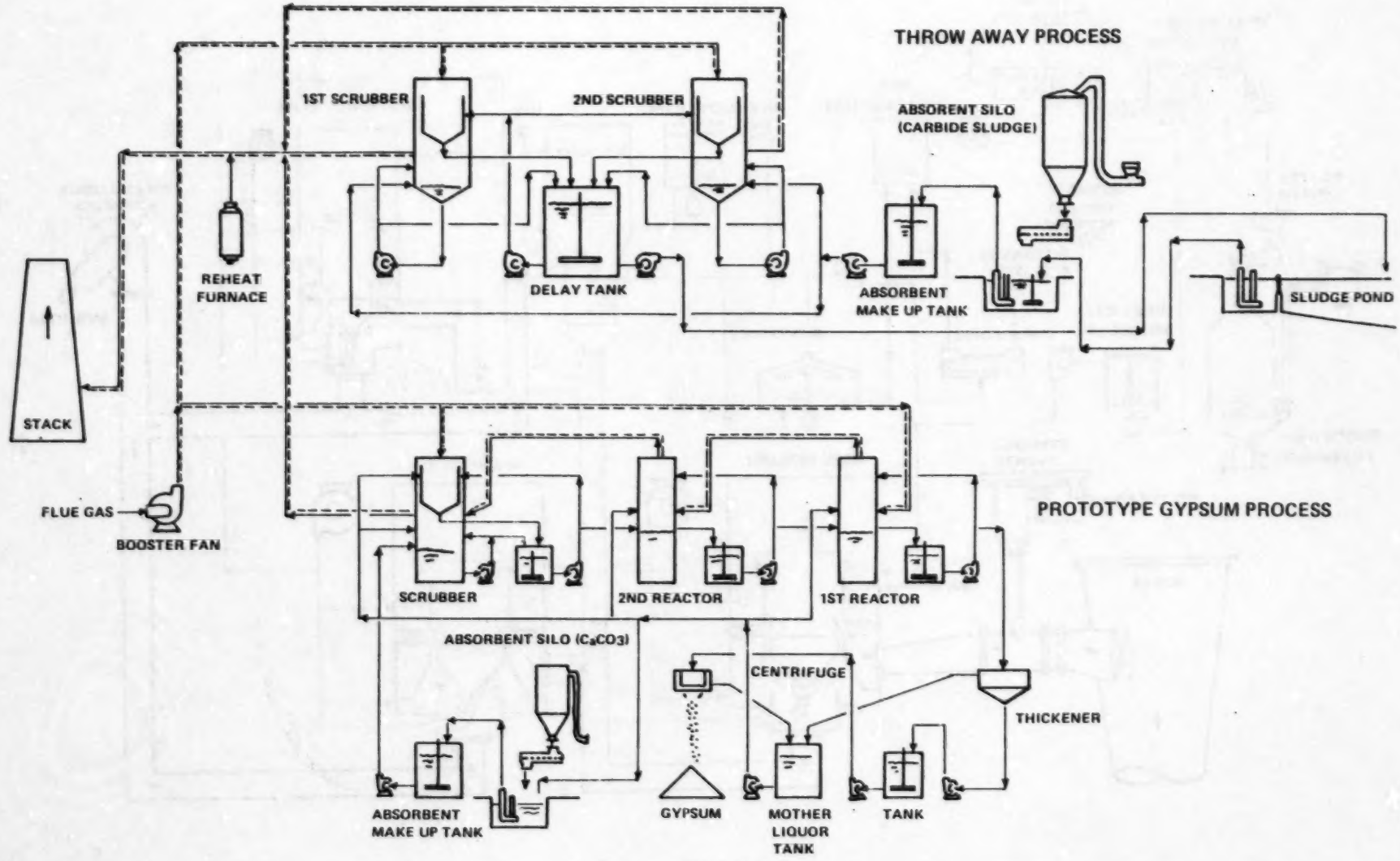

Figure 11.

MITSUI ALUMINUM COMPANY
MITSUI - CHEMICO LIMESTONE - GYPSUM PROCESS
FLOW DIAGRAM
UNIT NO. 2

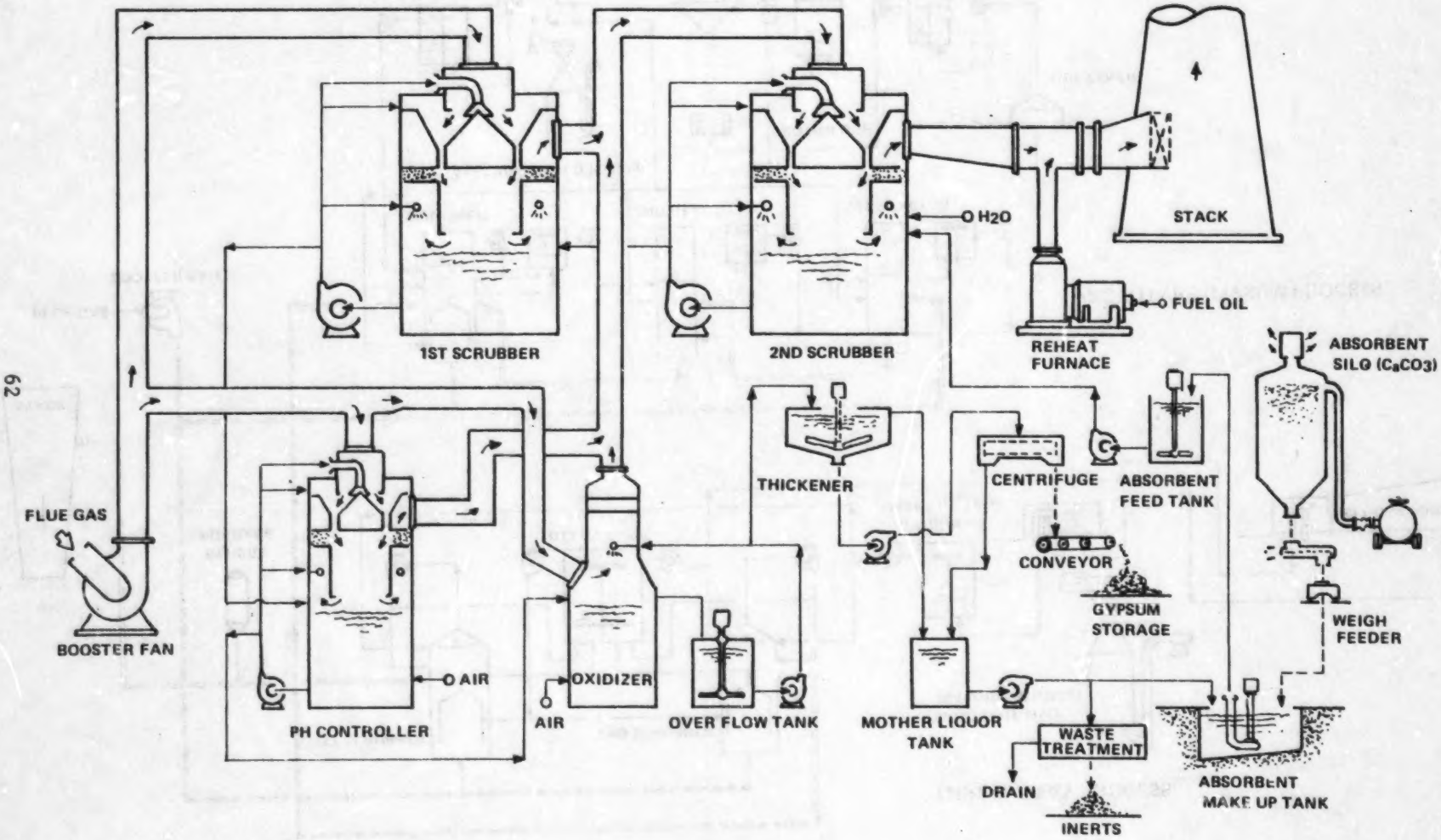

Figure 12.

Table 13

Mitsui Aluminum Company

Mitsui-Chemico SO_2 Removal System

Power Plant/FGD System Design and Performance Data

	Unit No. 1	Unit No. 2
Boiler		
Steam generation capacity (tons/hr)	490	550
Power generation capacity (MW)	156	175
Electrostatic precipitator efficiency (%)	98.6	98.6
Coal		
Heat value (kcal/kg)	5500-5800	5500-5800
Sulfur content (%)	2.4	2.4
Load variation (%)	100-50 (usually 100)	100-50 (usually 100)
SO_2 Control System		
Flue gas rate (Nm^3/hr	512,000	552,000
Inlet SO_x (dry ppm)	2100-2300	1900-2100
Inlet particulate (g/Nm^3)	0.6	0.6
Inlet gas temperature (°C)	136	138
Scrubber type	2-stage venturi	2-stage venturi
Scrubber capacity (Nm^3)	385,000 x 2	552,000 x 1
Absorbent	carbide lime	limestone
Outlet particulate (g/Nm^3)	>0.06	>0.06
Outlet SO_x at stack (dry ppm)	>200	>200
Average SO_2 removal efficiency (%)	90^+	90^+
Liquid purge rate (tons/hr)	90	20
Utility consumption		
Electric power (kw)	3650	4240
Water (tons/hr)		36.5
Bunker C oil (kl/day)	15	18
Limestone/lime (tons/day)	110	110
Catalyst (kg/hr)		20
Gypsum production (tons/day)		180
Availability (%)	100	99 (100 since 11/75)

Table 14

Mitsui Aluminum Company

Mitsui-Chemico SO_2 Removal System

Materials of Construction

Absorber	-	Carbon steel lined with FRP
Piping	-	Rubber lined (butyl)
Pumps	-	Rubber lined casing, cast steel impeller
Valves	-	Ball valves (316 L stainless, Unit No. 2) (304 L stainless, Unit No. 1) Butterfly and diaphragm control valves - rubber lined
Ductwork	-	Flake lined in low temp., saturated gas area carbon steel in high temp. area
Thickener	-	Rubber lined
Oxidizer	-	Flake lined
pH controller	-	Flake lined
Spray Nozzles	-	Open pipe 304 stainless (Unit No. 1) Open pipe 316 L stainless (Unit No. 2)
Stack	-	Phenolic resin lined
Centrifuge	-	Stainless steel basket
Dampers	-	Single Louver (high temp. area - carbon steel) (low temp. area - flake lined)
Mist Eliminator	-	4 pass polypropylene chevron

Table 15

Mitsui Aluminum Company

Mitsui-Chemico SO_2 Removal Processes

Typical Chemical Analysis of Reagents/Products

	Unit No. 1		Unit No. 2	
Fraction (% weight)	Carbide Lime	Waste Sludge	Limestone	Gypsum
$CaCO_3$	0.24	1.73		
CaO			55.3	
$Ca(OH)_2$	91.40	5.10		
$CaSO_3 \cdot 1/2\ H_2O$	3.85	68.91		0.13
$CaSO_4 \cdot 2H_2O$	0.48	18.51		94.82
MgO			9.3	0.15
S_iO_2	1.43	5.35	0.3	
F_2O_3	0.48	0.50	0.2	
Al_2O_3	0.71	1.69	0.3	
Na_2O				0.076
HCl insoluble				2.34
Ignition Loss			43.0	

Table 16

Mitsui Aluminum Company

Mitsui-Chemico SO_2 Removal System

Investment and Operating/Maintenance Costs

	Unit No. 1	Unit No. 2
Investment (Yen)	1.1×10^9 0.7×10^9 25 MW prototype	4.0×10^9
Annual (Yen/kwhr)		
Utilities	0.443	0.515
Operations/Maintenance	0.113	0.111
Fixed Charges	0.283	0.780
Total	0.839	1.406

Electric Power Development Company

Tokyo Offices

Meeting on January 31, 1978 at 10:00 a.m. at EPDC's Headquarters.

Attendees

EPDC: Mr. Yasuyoke Nakabayashi, Senior Power Engineer Chief Manager
Mr. Toshio Harpase, Deputy General Manager, Thermal Power Department

Study Team: Jumpei Ando, M. A. Maxwell, T. M. Morasky. H. W. Elder

Background

The Electric Power Development Company, Limited (EPDC) is a government financed corporation founded in 1952 in order to mitigate the serious power shortage in the post-war period of economic reconstruction. The principal purposes of EPDC are to undertake the development of large scale or difficult power development schemes or multiple purpose projects incorporating integrated national land development plans. The company has total power development schemes valued at some 800 billion Yen, the major part of which were financed by the government. Since its establishment EPDC has completed 7000 MW of generating capacity at 50 sites which are located throughout the country. These include coal fired power plants constructed in accordance with the national energy policy of de-emphasizing the nation's dependence on foreign oil. The EPDC contributes much toward stabilizing the supply of electricity by the wholesale of energy produced at the nationwide plants to private electric utility companies serving their respective territories and by the effective operation of its plants and the interchange of power between regions.

Highlights of Meeting

The Electric Power Development Company as a matter of national policy has constructed a number of coal-fired power plants. Five coal fired units are owned and operated by EPDC at Isogo (2), Takehara (1) and Takasago (2). The total megawatt capacity of these units is 1280 MW. All of these units are equipped with limestone scrubbers producing a saleable gypsum product. Because of these scrubbers the EPDC has obtained large in-house expertise on limestone FGD. During our discussions with EPDC personnel an attempt was made to determine how this expertise has affected the company's philosophy on the design and operation of limestone scrubbing systems. It became apparent through our discussions that when ordering a scrubbing system from a supplier very general specifications, based on performance and fuel fired are given. They do not specify any scrubber availability figure. EPDC, however, expects the supplier to provide a scrubbing system that will have an availability that matches the availability of the boiler and turbine. EPDC requires a supplier of a scrubber system to correct and solve any problems in equipment and/or process that may occur within a year after acceptance of equipment. EPDC personnel feel that flue gas velocity in a scrubbing system is a major design variable that is most responsible for reliable scrubber operation. Velocities should be kept at a minimum value to protect reheater sections by minimizing mist carryover from the scrubber vessels. It is EPDC's philosophy to provide system redundancy for pumps only. They usually specify one extra pump for every four. They also feel that to have a good operating scrubber requires a good operating precipitator to minimize erosion problems. During the meeting EPDC personnel stated that scrubbing coal containing 0.7 percent sulfur or less offers no scaling problems which they feel are partial function of process type. However, when scrubbing coal greater than 0.7 percent sulfur some degree of scaling may be "inevitable," but controllable to the extent that scrubber outages would not be required between annual boiler maintenance shutdowns. For the two new coal fired units planned for start-up in January 1981, EPDC anticipates firing a 1.2 percent sulfur coal blend. They are planning not to exceed 1.3 percent sulfur in these new units.

As a national policy EPDC must use coal for future power plants. If they use a domestic coal, the government pays all depreciation costs of the scrubber (seven year depreciation) and a scrubber maintenance cost for seven years calculated at three percent of the initial capital investment. Since EPDC is planning on a foreign coal supply in their two planned units they will not qualify for the subsidy.

It was estimated that thirteen percent of the total capital investment of a power plant is for FGD. A typical 500 MW unit costs approximately 150,000-180,000 Yen/kw. An FGD system constructed on a 500 MW unit would cost approximately 20,000 Yen/kw. Scrubber operating costs were estimated by EPDC to be about 1.2 Yen/kwh while total costs of producing electric power, including FGD run about 10.0 Yen/kwhr.

Overview of Coal Fired Scrubbers at EPDC

All three utility sites of EPDC using scrubbers for sulfur dioxide control on coal-fired boilers were visited. It was felt that these could best reflect the status of the technology and the information obtained would more realistically respond to the needs of the utility industry in the United States. As a result of these plant visits a number of observations were noted that might contribute to the high SO_2 removal efficiencies and reliabilities of these scrubbing systems.

Both Japanese suppliers and users of FGD systems consider a scrubber to be a chemical process. Operation of scrubbers requires constant control by personnel trained to operate a chemical process. The raw materials flowing into these chemical processes are controlled carefully to minimize upsets to the chemistry and to operate them as close as possible to design conditions. To maintain a relatively constant SO_2 inlet, the utility owner of an operating scrubber blends his coal prior to firing. In addition all scrubbers operating on coal-fired units had electrostatic precipitators operating ahead of them to minimize the dust loading into the scrubbers. The precipitator performance is not allowed to degrade even though the scrubbers could act as "polishers" for particulate removal. They believe that allowing excessive amounts of fly ash into the

scrubbing system will result in increased solubilities of unknown compounds that may affect the chemistry of scrubbing as well as increase the erosive characteristics of the slurry to a greater extent than what was designed for in the scrubber. In addition, users of limestone scrubbers in EPDC buy dry pulverized limestone with strict specifications on size (over 90 percent through 325 mesh) and chemical composition (less than 1 percent of inerts and less than 1 percent magnesium compounds). This allows for a constant and reliable reagent feed into the scrubbing process.

EPDC hires specially trained personnel to operate their scrubbers and do not rotate them into the power plant for boiler operation. In fact, they contract a subsidiary company for the personnel required to operate the scrubbers at Isogo, Takasago and Takehara. It appears each plant has its own separate contract with the subsidiary company since at some plants the contract included scrubber maintenance as well as its operation and at others it included only the operation.

Proper control of scrubbers in the EPDC system dictates that the chloride concentrations in the scrubbing slurries are not allowed to increase to levels considered potentially harmful either to the materials of construction, the process chemistry and/or the gypsum product. This proper chloride level is maintained by purging water from the process and therefore opening the water loop somewhat resulting in not only low chloride concentrations but may also contribute to subsaturation of calcium sulfate, thus minimizing scaling potential. This factor can be considered one of the most helpful in operating their scrubbers in a reliable manner.

All the scrubbers operating on these coal-fired units purge a certain volume of water. Usually these purges are treated and must meet standards for pH, BOD and COD as well as suspended solids; however, no limit has been placed on dissolved solids for these blowdown effluents.

In the United States, it had generally been felt by many that most Japanese scrubber systems operated open loop. However, in comparing the blowdown figures with the solids generated it appears that some plants operate with much tighter water loops than some in the United States and others operate much more open loop. For example, the ultimate settled solids in a limestone scrubbing system in the United States employing ponding is about 50 percent with no blowdown. To define the coal-fired Japanese systems so that they can be compared on a equal basis to those in the United States it is necessary to relate the reaction products (gypsum) produced in the scrubber to the purge water blown down to calculate an effective pond disposal concentration. These theoretical calculations indicate the effective pond disposal solids concentrations for the Japanese scrubbers on the EPDC coal fired units visited to be:

Isogo - approximately 29 percent solids
Takasago - approximately 51 percent solids
Takehara - approximately 46 percent solids

These results show that the Takasago and Takehara systems are relatively tight in their water balance and could be considered closed loop if operated as a pond disposal system in the United States. However, the Isogo scrubbers appear to be somewhat comparable to some systems operating in the United States employing blowdown.

The EPDC scrubbers operating on coal-fired boilers are treating flue gas streams that are generally more dilute with respect to SO_2 concentrations than are currently being treated by many U.S. utility scrubbing systems. Japanese FGD systems have been employed typically to treat flue gases having an SO_2 inlet concentration range of 400-2300 ppm. These are significantly lower than the 1600-4000 ppm inlet SO_2 concentration requiring scrubbing by many U.S. utility installations in the Midwest and East which present inherently more difficult set of operating conditions.

It is also significant to note that because of the somewhat lower heating value of the Japanese coals they must be fired at a higher burn rate to generate the same amount of power as the typical U.S. utility burning Midwest or Eastern coal. Such low grade coals produce a larger volume of flue gas and greater SO_2 emissions per unit of generated power. On a megawatt basis, therefore, the EPDC scrubber system (as well as power plant) equipment capacity is greater and capital and operating costs are higher than for the typical U.S. utility burning higher heating value coal of a comparable sulfur content.

In conclusion, Japanese scrubbers as typified by the EPDC coal fired installations do work efficiently and reliably. The reasons for this success are numerous and varied, ranging from the dedication of the Japanese suppliers/users to the generally less severe scrubbing conditions existing at Japanese installations. However, it appears that the major reason for this success is the utility user's willingness and ability to spend the necessary money to buy the best scrubbing systems available for use at a specific site and to operate them in the manner for which they were designed.